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U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

The Selection of Preferred Metric Values for Design and Construction

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The Selection of Preferred Metric Values for Design and Construction

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FOREWORD

This Technical Note, dealing with "The Selection of Preferred Metric Values for Design and Construction" was prepared in response to a request from and partial funding by the Naval Facilities Engineering Command (NAVFAC), Department of the Navy.

The project was developed from the appreciation that metrication in the United States construction community will involve two related but separate technical considerations: a change to metric (SI) units of measurement, and a change to new numerical values. In any combination of a number and a reference unit--a numerical value--the number invariably assumes increasing significance over time in the processes of communication, measurement, verification, and computation. The simpler the numbers, the faster, easier, and more accurate will be the activities involving measurement and calculation. In the customary system of measurement, numerical values have their own lore and widely understood meanings, and it is the temporary loss of people's numerical familiarity and recognition that has been described as the greatest single obstacle to the change to metric measurement.

It is widely recognized that a transfer to a metric technical environment based upon a "soft conversion" -- that is, no change other than the description of physical quantities and measurements in SI units -- would cause considerable longer term problems and disadvantages due to the encumbrance with the resulting awkward numbers. The overall costs of soft conversion could greatly outweigh any savings due to its short term expediency.

The purpose of this study is to provide a rational basis for the evaluation and selection of preferred numerical values associated with metric quantities. Precedent has shown that the change to SI units can be accompanied by a change to preferred values at little or no extra cost, especially in specifications, codes, standards, and other technical data. By comparison, if the opportunity for one-time rationalization is missed, it is almost certain that a subsequent change will need to be made at some future time, with the concomitant extra upheaval and cost.

This Technical Note contains background to numerical considerations in a decimal and SI measurement context; it discusses various "preferred number alternatives" in a variety of decision situations, and provides a methodology for the selection of preferred metric values by means of a manual or an automated approach. While the suggested methods of application are designed to pinpoint preferred values, they will <u>not</u> preempt or prejudice any final decisions by those responsible for the preparation of metric technical data. Although the techniques were developed predominantly for application in construction and related engineering, they may also be applied in other sectors of the community.

The work may be further extended through the development of a computer-based approach to the conversion and rationalization of standards and other technical data, and the main ingredients of such an approach have been outlined. The use of high-speed electronic data processing techniques in the conversion and rationalization of technical information should expedite and simplify the very substantial task of preparing, within a reasonable time frame, a comprehensive metric technical data bank.

The author of this Technical Note is Hans J. Milton, B.Arch., M.Bldg.Sc., M.B.A., FRAIA, technical consultant to the Center for Building Technology on metrication and dimensional coordination in building. Mr. Milton is on loan to the National Bureau of Standards from the Australian Government Service, where he holds the position of Assistant Secretary in the Department of Environment, Housing and Community Development. During the period from 1970 to 1974, he was a leading figure in the Australian change to metric measurement in building design and construction, and the Chairman of the Government Construction Sector Committee of the Australian Metric Conversion Board.

During the review process, constructive comments were provided by NAVFAC; Dr. D. Shier, Mr. L. Barbrow, and Ms. S.A. Berry of the National Bureau of Standards; and, Professor Cornelius Wandmacher of the University of Cincinnati.

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EXECUTIVE SUMMARY

The principal task in the conversion and rationalization of technical data during the change to SI--the modern metric system--is the determination of "preferred metric values," that is, the selection of preferred numbers to be used with correct SI units.

Exact metric equivalents of customary values will invariably yield complex numbers in the SI expression because of the different bases of the customary system and SI. It is, therefore, a matter of research and judgment in each instance to decide what departure from the exact conversion is feasible or acceptable in product sizes or technical information, so that the metric description will be in simple and/or preferred numbers. In this analysis, technical as well as economic considerations should be taken into account. However, since most customary benchmarks were set on the basis that they provided convenient reference values, rather than on the basis of scientific considerations, <u>no</u> customary value ought to be regarded as sacrosanct when it comes to metrication. The values that are selected should complement and enhance the decimally based and international measurement system as they will remain for many years as key references in a metric world.

Thus, a "hard conversion" to new and preferred values is generally the better solution overall, even though such a change may have greater initial cost than a soft conversion. A "soft conversion," which makes no real changes other than using SI reference units in the expression of magnitudes, may appear to be the least complicated approach to change, but it will almost always be counter-productive, and may well require a second and later change to preferred values. This is because cumbersome numbers tend to complicate all processes of measurement, verification, calculation, and communication. A hard conversion, by contrast, can frequently be accompanied by "rationalization," such as a reduction in the variety of products or requirements while providing more sensible steps, or the unification of differing requirements into preferred metric standards.

This Technical Note has been prepared to assess number systems and number preferences that are compatible with the decimal structure of SI, and to provide a set of guidelines for the identification and selection of preferred values during metrication.

The <u>Introduction</u> sets out general considerations in the conversion of technical data to metric [SI] units, discusses briefly the key management aspects in metric data development, summarizes the objectives of the study and the contents, and lists those activities normally required in the selection of preferred metric values.

The technical information is divided into three parts.

<u>Part 1: Number Systems and Properties, Metrication Impact, and Conversion Strategies</u>, provides general background information leading up to the identification of alternative conversion or rationalization strategies. It discusses the basis of the universally accepted decimal system of numbers and number symbols, and the extension of decimal concepts into measurement applications, especially in the modern metric system--SI. Number relationships and properties are examined, and some general preferences pointed out. The impact is assessed of the conversion to metric units in technical information and special considerations are highlighted. A clear distinction is made between four types of conversion activity: exact conversion, soft conversion, hard conversion, and rationalization. Part 1 concludes with a synthesis of the four types of conversion activity into two approaches: a restricted approach in which existing products, requirements, or data are generally retained; and, a free approach in which entirely new and rationalized product ranges, requirements, or technical data are developed. Figure 1 (page 14) illustrates how these approaches lead to either convenient values or preferred values.

<u>Part 2: Preferred Number Concepts for Individual Values and Series of Values</u>, examines various concepts of "convenient numbers" and "preferred numbers" in measurement, and the use of such numbers in conversion decisions during the change to SI units. Numerical values are separated into three categories: individual values, which exist on their own and are independent from other values; related individual values, which

are, or may be, part of a set or series of values; and, series of preferred values. Figure 2 (page 16) illustrates that individual (independent) values would normally be chosen from convenient numbers, while series of preferred values would be selected from a suitable series of numbers. Preferred dimensions for use in building form a set of preferred values based on arithmetic increments of selected units of size.

Convenient numbers represent preferences of simple numbers which are multiples of 5, 2, and 1, and their powers of ten in a descending order. These numbers are particularly useful in a decimal measurement environment. Table 1 (page 17) provides a selection matrix with up to seven preferences for each numerical range. An example of the use of convenient numbers to rank alternative metric values is given on page 19.

Preferred dimensions in building form a special set of preferred values which have been included because of the significance of coordinated linear dimensions in building and engineering applications. All such dimensions have an arithmetic relationship to the basic unit of size--or module--of 100 mm, or selected multimodules and submodules. The criteria for selection of preferred dimensions and dimensional preferences are discussed in Section 2.4, and Table 6 (page 25) provides a selection matrix for preferred metric dimensions in building.

Series of numbers for use with SI are examined in Section 2.5, including arithmetic series, geometric series, special purpose series (such as the 1-2-5 series), the Renard series of preferred numbers, and the internationally agreed ISO preferred number series. Because of the potential they provide for rationalization during the change to SI, the ISO preferred number series are discussed in detail. Table 7 (page 31) shows all the basic series [R5, R10, R20, and R40], and the more rounded series [R'10, R'20, and R'40 for the first rounding; and R"5, R"10, and R"20 for the second rounding]. Further, limited series and derived series are discussed, and Section 2.5.10 illustrates how a given range can be covered by preferred numbers from different series. In Britain and Australia special sets of numbers for use as preferred sizes [linear dimensions] in engineering have been developed by combining geometric and arithmetic increments, and these approaches are discussed briefly in Section 2.5.11. Part 2 closes with a comparison of the features of geometric series and arithmetic series.

Part 3: A Methodology for the Selection of Preferred Metric Values in a Manual or an Automated Approach, was developed to permit the practical application of numerical preferences in the conversion and rationalization of technical information. The following processes are discussed: identification and listing of all numerical values requiring conversion; analysis of the nature of each value and the assessment of any dependencies; conversion of existing values and the rounding of such conversions, illustrated by means of a sample schedule; and, the rationalization of a set or series of values to derive the optimum [metric] functional range. While all techniques can be used in a manual [desk-based] approach, they also lend themselves to the application of automated [computer-based] processing which will facilitate the search for metric "preferences," as well as reduce errors in calculations.

The automated techniques suggested in this Technical Note are designed to assist in the selection processes by identification and comparison of all [preferred] metric values that occur in the vicinity of direct conversions, and through the ranking and tabulation of alternatives. What is required in an automated approach is a "sensitivity assessment" of the magnitude of change that existing values can be subjected to during the process of conversion. This can be done in two ways. The first, the assignment of an "index of criticality," involves the assignment of a limit to the variance that can be accepted so that the most suitable value can be chosen from within that variance. The second, the selection of "sensitivity bands," is an open-ended approach in which the most preferred values are tabulated for a group of variances--or sensitivity bands--and the final selection is a matter of value judgment by a group or standards committee, based upon a comprehensive schedule of alternatives. The first approach involves consensus prior to the selection, the latter approach requires consensus afterwards.

Section 3.8 sets out a model for a fully automated approach, in which each measurement statement can be matched to specific numerical preferences, as shown in Table 12 (page 62). Section 3.9 lists all steps required in the development of a fully automated approach. Although techniques for the identification of preferred metric alternatives can be automated, the final responsibility for the selection of metric values remains under the control of the appropriate metric group or standards committee, and it can always be modified to take account of specific market factors.

Appendixes have been included to provide: a glossary of terms; examples of the application of preferred number series in international and foreign standards; simulated output data for an automated approach; and, a comprehensive set of references.

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ABSTRACT

This Technical Note contains a comprehensive examination of considerations involved in the selection of preferred metric values during the change to SI in the U.S. construction community. It has been prepared to assist those engaged in the conversion and rationalization of technical data for use in design and production to make informed judgments during the selection of metric values.

The adoption of preferred metric values and the concomitant rationalization of the technical data base will be one of the main benefits of the change to metric (SI) units. The principal aim is to encourage the choice of simple, convenient, or preferred metric values and ranges of rational values, rather than exact or marginally rounded soft conversions of existing values which will generally require a second change to more workable numbers at a later stage. The Technical Note has three parts:

1) background information on number systems and properties of numbers, metric impact, and alternative conversion strategies;
2) alternative preferred number concepts for individual values, sets of related values, and series of preferred values; and,
3) a methodology for the determination and selection of preferred metric values in technical information by means of a manual or an automated approach.

Key Words: Convenient numbers; metrication; number systems; preferred numbers; rationalization; selection of metric values; series of numbers; SI.

INTRODUCTION

General Considerations

The United States is now at the threshold of planning for conversion to the modern metric system--better known as the International System of Units, or SI. The process of conversion is often referred to as "metrication."

A key element in metrication of building and engineering--probably the most important aspect--is the need to restate in a timely fashion the entire technical data base in correct metric terms. A large part of these data is contained in the myriad of specifications, standards, codes, and handbooks in daily use by the various groups involved in building design, materials production, construction, or building control.

The metrication of technical data is not a simple task. The change to SI units means that new values as well as unit names will replace descriptions that have long been familiar to the building and engineering community. The "new numbers" have to be chosen with care because they are likely to remain an integral part of the metric building scene for a long time. It is essential that this aspect and its implications be properly understood by management and professionals alike.

While it will take some time before people acquire full familiarity in a metric environment, convenient and preferred values for use in key activities will facilitate the transition and the adjustment processes. "Simple" numerical values can be recognized more easily, memorized more effectively, and used expeditiously in technical calculations--thus they will "simplify" the changeover. To go into a metric world with merely a "metric veneer"--that is, customary values directly converted to SI--would lead to awkward numbers and, therefore, would be counter-productive in the longer term. It would also waste a unique opportunity to utilize the change to SI as a means to select "preferred numbers or series of numbers" which reflect optimum values and provide technical and/or economic advantages to the community. The process of choosing "optimum" new criteria is generally referred to as "rationalization."

In other countries that have preceded the United States in metrication, various conversion strategies were tried during the change to SI. The general experience was that with "soft conversions" [no actual change other than the expression of magnitudes in SI units] pressures soon developed which demanded a second change to more suitable and preferred metric values, thereby greatly increasing both the cost of metrication and the disturbance caused by it. On the other hand, where changes were planned properly, a "hard conversion" to new preferred values, and/or "rationalization" of products or requirements could be effected at little or no extra cost. It was also found that there were many situations, where a "convenient" metric value was all that was needed, because product sizes or characteristics could remain independent of measurement preferences.

Due to overriding economic, technical, or legal constraints, optimum solutions are not always possible during metrication. To provide the most useful metric legacy for all future construction activity in a metric United States, every effort should be made to arrive at "preferred metric values" where their adoption and use is feasible.

The Metrication Process

The change to SI involves an extensive process of identification, analysis, conversion, rounding, and rationalization of numerical values associated with the measurement of physical quantities. To ensure that technical data are prepared on time and in the required sequence, these activities should be planned, coordinated, and controlled within the overall context of an industry and/or corporate metric program.

A number of management aspects impact on the metric data development activities:

[a] Assignment of Responsibility for Metrication

In the conversion of specifications, standards, codes, or other technical data, it is essential that the responsibility for technical tasks and decisions is established early on, leaving no doubt as to accountability.

[b] Establishment of Liaison

To ensure that metric [SI] values are not in conflict in related or derived technical data, contact and liaison need to be established between different groups engaged in technical metrication of related documents. Unilateral conversion or rationalization activity is almost certain to lead to differing and incompatible values for similar applications.

[c] Establishment of Priorities

There is a "natural hierarchy" of technical data for use in the building construction community. In the international sphere, the International Organization for Standardization [ISO] has adopted a system of "levels" to indicate relationships of standards. Fundamental standards comprise Level 1; they provide inputs into wide-ranging standards at Level 2, which, in turn, generate data for specific standards at Level 3.

It is suggested that metrication of fundamental and wide-ranging standards ought to take precedence over the development of specific metric standards and other essential reference documents. Priorities should be established to ensure that the important technical data are developed first, thus providing essential inputs into dependent information.

[d] Standardization of Approaches to Metrication

It is highly desirable and advantageous to ensure that similar practices and principles are adopted by all parties engaged in metrication of specifications, standards, codes, and technical handbooks. Ideally, conversion activity should be based on a standardized format and approach.

This Technical Note contains recommendations for a methodical and consistent approach to the selection of "preferred metric values" in technical information, and thus provides part of a "general metric practice" for the development of metric technical data. While the methodology is primarily intended to assist in the conversion and rationalization of existing data, the technical information in Part 2 may also be applied in the determination of preferred metric values for new products or requirements.

[e] Critical Assessment of Measurement Values During Metrication

Conversion procedures should allow for the critical assessment of the technical basis of measurement values and/or their magnitudes.

In the initial assessment of measurement values the following questions might be asked:

i. What is the purpose [objective] of each measurement statement?

ii. Could such a purpose be expressed differently or in a more concise manner?

iii. Are the circumstances [conditions] that have dictated the magnitude, limits, or tolerances of the customary value(s) still valid or relevant in a metric context?

iv. Is a research effort required or desirable to ensure that metric values are based on the best available technology and current conditions?

v. Is the measurement statement necessary at all?

Historical considerations which have influenced technical data should be examined to prevent outdated approaches or inconsistencies from being transferred to the metric value or values.

Similarly, economic aspects need to be considered to assess the impact of various metric alternatives--and, especially, any rationalization proposal--on production, inventories, distribution systems, design and/or construction practices, building control, as well as international trade of building products or building technology.

Objectives of the Study

The principal objective of this Technical Note is to provide information which will assist individuals or groups engaged in the preparation of technical information and standards in the determination of preferred metric values [and dimensions] for use in construction and engineering applications.

The methods described are designed as "decision aids" for the selection of suitable metric values in the conversion and rationalization of technical information. These decision aids are based on the identification of numerically preferred SI values, and their comparison with the direct equivalents of customary values.

By following a decision sequence, the need for and likelihood of "random selections" is minimized. It is probable that with a structured approach modifying factors will be identified rather than overlooked. The building community can make a "hard conversion," by encouraging the selection of preferred values--wherever practicable--rather than opting for the "least change approach" of a soft conversion.

A general objective of the methods suggested is to preserve full responsibility for the final selection of the most appropriate metric alternative among those committees or working groups which have the task of preparing metric technical information.

Outline of Contents

This Technical Note deals with the background to numerical considerations in a decimal and SI measurement context; outlines various preferred number alternatives; and, provides a methodology for the selection process involving preferred metric values in specifications, standards codes, and other technical data. The selection process can be based either on a manual approach, in which all calculations are made with conventional calculating equipment and entered manually into a conversion schedule, or on an automated approach, in which activities are mechanized by the use of an analytical program and data processing techniques.

Explicit examples and guidance for the application of numerical selection techniques are provided as a working tool for use by those who have the task of converting technical data or documents to metric [SI] units. The format used for the presentation of technical data and the examples shown have been included for illustrative purposes only. A standard format for use in the conversion of technical information could well be developed under the auspices of the American National Standards Institute [ANSI], or the U.S. Metric Board.

While the techniques are intended primarily to assist in the conversion of existing information, the concepts discussed in Part 2 may also be applied in the selection of preferred metric values for entirely new standards and technical data.

Appendixes provide a glossary of terms; examples of the use of preferred numbers in existing standards; typical conversion schedules; and, relevant references.

The Selection Process Involving Preferred Metric Values

To undertake the selection of preferred metric values, it is desirable to have an understanding of the major properties of numbers and number series, as well as the structure of SI. In a methodical approach to the identification and selection of preferred values the following activities typically need to be organized and accomplished:

[a] the identification and listing of all measurement sensitive statements;

[b] the assessment and categorization of the nature and/or dependencies of each of the values to be converted;

[c] the determination of the implied precision and/or limits of acceptance for customary values as a measure of their "sensitivity" to change and guide to permissible variance;

[d] The selection of appropriate SI working units and associated correct conversion factors to determine metric equivalents;

[e] the application of a system of numerical preferences--such as convenient numbers, preferred linear dimensions, or preferred number series--to select metric values or a range of values of equal or greater numerical simplicity;

[f] the listing of alternative conversion options in a schedule which includes:

i. metric values in their order of preference
ii. a statement of the quantitative change, in percentage terms, associated with each alternative
iii. a reverse conversion of each metric alternative into customary units, for recognition purposes of the quantitative change in absolute terms;

[g] the choice of the most appropriate value by consensus procedures, where applicable;

[h] the communication of such choices or proposed choices to all groups concerned with the use of such values in dependent technical decisions;

[i] the issue of draft metric technical documents for public comment and balloting [this process is not required if the technical information is prepared entirely for use within the originating organization];

[j] the publication of agreed metric technical documents, in which all comments and suggestions have been taken into account.

The entire process can be facilitated and speeded up by an agreed approach that meets the goals outlined above. The widespread support for the selection of preferred metric values is essential to ensure that calculations, technical activities, and measurement-oriented work in the permanent metric environment are simplified rather than complicated.

PART 1: NUMBER SYSTEMS AND PROPERTIES, METRICATION IMPACT, AND CONVERSION STRATEGIES.

1.1 General

There are two principal factors in any measurement statement: a "number" and a "measurement unit." The number always is placed first and it indicates the magnitude of a measurement as a ratio of the reference quantity described by the measurement unit.

In the International System of Units--SI--there is only one unit for each physical quantity, and all units in the system are coherent as they relate to each other on a one-to-one [or unity] basis. However, the "reference quantity" can be changed decimally by the attachment of a prefix, thereby providing "working units" which yield the most suitable numerical values in calculations or measurement.

Numbers represent an abstraction - they have no physical existence and are meaningless on their own, as they are independent of any measurement system. But as soon as they are combined with a measurement unit or unit symbol, they identify a specific value or magnitude. Modern technology could hardly exist without "numerical values" in the communication process to indicate magnitudes in measurement, calculations, or specifications. Most measurement activities and computations involve a continuous process of number verification. In the construction and engineering industries, numbers provide the principal representation of geometric or mechanical quantities.

The impending conversion to SI will alter all familiar numbers that have been associated with the customary measurement system. (This is due to the different bases of SI and the customary system, which requires the use of "conversion factors" to express data from one system in the other.) The conversion factors are generally complex numbers and, therefore, the direct conversion from one system to the other leads to numerical values that lack simplicity. It follows that one of the key tasks in the change to SI--the metrication process--is the selection of "preferred metric values," representing the combination of preferred numbers with correct SI units.

Before the selection of metric numerical values is attempted, it is desirable to understand the basis of our number system, its properties, and the special features and numerical aspects that are associated with SI. These considerations are discussed in Part I, which also deals with various "metrication strategies."

1.2 Number Systems and Symbols

In the history of mankind, various number systems and symbols for their representation have been in use. While remnants exist of the vigesimal system [using the base twenty], the duodecimal system [using the base twelve], and the quinary system [using the base five], only three number systems have an impact on activities in the twentieth century: the sexagesimal system [using the base sixty]; the decimal system [using the base ten]; and, the binary system [using the base two].

The sexagesimal system was first used by the Babylonians and still survives to the present in the subdivision of time and angular measurement. The decimal system has come to dominate all the numerical processes, and has been extended into the measurement of money and all physical quantities. The binary system uses only two symbols, the numerals 0 and 1. This system has come into widespread use in high-speed electronic calculating processes, because the binary form can also be used to represent a "yes-no" or "true-false" decision logic. However, it is unlikely that the binary system will ever supplant the decimal system of numbers and number symbols--a system which has become universally adopted by mankind, and may be regarded as the nearest approach yet to a universally acceptable language of communication by symbols.

1.3 The Decimal System of Numbers

The "decimal" system, using the base ten, is almost certainly derived from man's early use of his ten fingers or digits as counters. All Indo-European languages use a decimal base of numeration, as do Semitic, Mongolian, and most primitive languages. Independent words are used for number words [one to ten, hundred, thousand, million, etc.]; however, in some languages, such as French, a special word for twenty is introduced. All other numbers are verbalized by combinations [compounding], including some contractions for multiples of ten.

The representation of numbers by symbols can be found in the earliest records of man. While the Greeks and Romans used a decimally based word structure for numbers, they adopted letter numerals for their representation. Roman numerals are a set of symbols of quinary character, with only seven symbols between one and one thousand-- I = one; V = five; X = ten; L = fifty; C = hundred; and, M = thousand. Numbers in between or larger than one thousand are formed by a system of addition or subtraction. For example, <u>1978</u> requires ten letter numerals: <u>MCMLXXVIII</u>. Roman numerals were used exclusively in Europe until 1000 A.D., but were gradually replaced over the next five hundred years by <u>Arab numerals</u> [of Hindu-Arabic origin], which clearly proved to be superior in all forms of calculations.

The Hindu-Arabic system of expressing <u>all</u> numbers by combinations of ten symbols [figures], with each symbol having an absolute value, as well as a value of position, is a profound idea that has lent great simplicity to all computations. This system certainly must rank as one of the greatest inventions of mankind.

In decimal position notation, each number is written as a linear combination of powers of ten, for example: [hundred twenty-three thousand four hundred fifty-six]

$$\underline{123\ 456} = 1 \times 10^5 + 2 \times 10^4 + 3 \times 10^3 + 4 \times 10^2 + 5 \times 10^1 + 6\ [\times 10^0]$$

The position of the digit to the left of the decimal marker--the final numeral in integers--indicates the power of the base ten [or radix], starting from 10^0. Approximately 400 years ago, this concept of positioning was extended systematically to include decimal fractions [or decimal parts], using the same position logic, but applied to negative powers of ten and starting with the power 10^{-1} for the first digit to the right of the decimal marker. Decimal fractions make it possible to accurately express divisions, complex numbers, and all values smaller than unity [one].

Because of the numerous advantages enjoyed by the perfected "decimal positioning method," the decimal system was gradually adopted by more and more countries. The use of the Arab numerals seems to have been a major factor in the dominance of Europe in cultural and scientific matters. Without their use, technological advances probably would not have been possible. The process of mechanized printing, discovered in Europe during the fifteenth century, helped to unify the form of the symbols--or figures--used to represent the ten digits in the decimal system.

The number "ten" is not the best number in terms of divisibility [it is divisible by 2 and 5 only], and thus is inferior to "twelve," which is divisible by 2, 3, 4, and 6. However, the universality of the decimal system has now been established so firmly that it is unlikely to ever be supplanted.

1.4 Extending the Decimal Concept into Measurement

When the power of the decimal system of numbers was recognized in the sixteenth century it was but a short step to suggest its use as the basis for structured relationships in measurement systems involving physical quantities and money.

The first decimal system of currency in the world was adopted by the United States in 1785, when a coinage plan involving the dollar and cent as currency units was agreed to in Congress. Actual coinage was minted in 1792. Thus, the U.S. became the first country to demonstrate the practicality and advantages of the modern decimal system in a measurement application. All countries in the world have followed this decimal pattern; one of the most recent being Britain, which changed to decimal currency in 1971.

A decimal system of measurement was first suggested in 1585 by the Flemish inspector of dykes and mathematician, Simon Stevin, who also developed the concept of decimal fractions. It was not until after the French Revolution, however, that a workable system was proposed and accepted by the French National Assembly. In this system, the fundamental unit of length was called the "meter" [French: mètre], equal to one ten millionth part of the meridian quadrant intersecting Paris. A key factor in the development of the "metric system" was the deliberate decision to fully complement the decimal number pattern by a system of generally applicable "decimal prefixes," representing powers of ten. In addition, units within the system--which at that time was only concerned with length, area, volume, capacity and mass--were related decimally through the properties of water, the most common substance on earth. A volume of one "liter" represented one thousandth of one cubic meter; and, by definition, when filled with water at the temperature of its maximum density had a mass [weight] of one thousand grams, or one "kilogram."

Based on these concepts, the metric system spread through the Napoleonic empire and was adopted progressively by more and more countries in place of their unrelated measurement systems. Gradually, the system was expanded to include units for all other physical quantities; and metric units for electricity, magnetism, and illumination are already in worldwide use. The development, in 1960, of the <u>International System of Units</u>--SI--as a rational, coherent, and "modern metric system" has induced nearly fifty countries over the past fifteen years to abandon their customary measurement systems and to convert to SI. The U.S. is the last significant link in the "metric conversion process," and the change to SI will ensure that there is <u>one measurement system for universal use</u>.

1.5 Special Features of SI

The modern metric system--SI--has a number of features which lead to greater numerical simplicity in the expression of measurement statements in technical documents:

[a] There is only one unit for each physical quantity.

[b] Units for all physical quantities are derived from 7 base units and 2 supplementary units.

[c] All derived units relate in a coherent manner to their constituent units--that is, the only numerical factor of proportionality in equations between units is "one."

Note: This differs significantly from the customary system which has a number of units for the elemental quantities length and mass, with independent or non-decimal ratios between such units. In derived units, the variety of derivations thus created is supplemented by additional special units. For example, where SI has one unit for pressure and stress, the customary system has many units.
A lack of coherence in a measurement system introduces one or several numerical factors into equations between units.

[d] All SI units can be changed decimally by the attachment of prefixes to form multiples or submultiples. Prefixes can also be thought of as a shorthand for exponential notation: for example, the prefix "mega" [M] attached to any SI unit always indicates a magnitude of 10^6 (or one million times); similarly, the prefix "milli" [m] attached to any SI unit always indicates a magnitude of 10^{-3} (or one thousandth).

[e] In the case of area and volume, the prefix is regarded as integral with the unit of length, so that squaring or cubing of a prefixed unit will square or cube the exponent of that unit; for example: 1 m = 10^3 mm; 1 m^2 = 10^6 mm^2; 1 m^3 = 10^9 mm^3. However, the only factor introduced is a decimal factor, so that the numerical value will have the same sequence of digits.

1.6 The Effect of Prefixed SI Units on Numerical Values

Preferred SI prefixes change the magnitude of the reference unit in steps of one thousand, either by enlarging or reducing the reference quantity. This means that in the description of a magnitude by a numerical value, a change in the prefix of the reference unit will change the position of the decimal marker, but not the digit in the number. Zeros are deleted or added as required by the rules of positioning.

This differs from the customary system, where a change in reference unit invariably introduces a non-decimal factor of proportionality and, therefore, results in a different numerical value. The differences are best illustrated by means of two examples:

Example 1: Proportionality of Units

SI Unit Symbol	Ratio
MPa	1
kPa	1 000
Pa	1 000 000

Customary System Unit Symbol	Ratio
$tonf/in^2$	1
$tonf/ft^2$	144
lbf/in^2 [psi]	2 000
lbf/ft^2 [psf]	288 000

(Note: U.S. tons of 2000 lb are used)

Example 2: Expression of a Magnitude

SI: 1.310 MPa = 1310 kPa
= 1 310 000 Pa

Customary System: 0.095 $tonf/in^2$ = 13.7 $tonf/ft^2$
= 190 lbf/in^2 [psi]
= 27 400 lbf/ft^2

The examples show that three SI units of pressure cover a far greater range than four U.S. customary units.

While the system of prefixes introduces opportunities for numerical simplification of metric technical documents, a number of factors should be taken into consideration:

[a] As a general rule, the more "compact" a numerical value, the more useful it will be in technical applications. However, the decimal marker must be taken into account in any assessment of "compactness," as it uses a full space in typing or computer printout.

[b] The choice of an appropriate prefix generally makes it possible to select numbers between 1 and 1000 to express magnitudes.

Where a value is smaller than "one," it can be enlarged by a ternary power of ten [such as 10^3, 10^6, etc.], by using a smaller reference unit. Often this has the advantage that digits behind the decimal marker can be reduced or eliminated; for example: 0.750 m = 750 mm; 0.125 MPa = 125 kPa; 0.2345 kJ = 234.5 J.

Where the numerical value is larger than one thousand [1000], and it is of advantage for reasons of consistency or numerical simplicity to choose a larger reference unit, the numerical value can be reduced by a ternary power of ten. However, since the prefix only changes the position of the decimal marker, moving that marker to the right may introduce decimal parts [decimal fractions] in some instances; for example: 125 000 Pa = 125 kPa = 0.125 MPa; 2438 mm = 2.438 m; 750 W = 0.75 kW.

[c] Circumstances will frequently dictate the selection of numerical values with numbers <u>outside</u> the range 1 to 1000; either because an industry has selected a particular working unit, or for reasons of consistency in calculations, presentation, and tabulation.

Note: The use of the millimeter (mm) as working unit for linear measurement in building construction will lead to four and five digit numbers in the description of building dimensions; however, it has the advantage that decimal fractions are avoided, and that all dimensions from small thicknesses and tolerances right up to large building dimensions can be shown by one unit and, where no ambiguity can arise, such as on suitably marked drawings, by <u>numbers only</u>.

[d] In some instances, the general metric simplicity will be more limiting than the features in customary measurement, and this needs to be recognized in the selection of numerical values with SI units.

For example, the prime number "5" used with an SI unit can only be transposed decimally to "5000" [in some special cases "500"] by the use of a different prefix--the numeral 5 will remain unaltered. In customary measurement, because of the non-decimal ratios between units, <u>5</u> feet can be transposed to <u>60</u> inches [a much more useful and highly divisible number], and <u>5</u> pounds can be transposed to <u>80</u> ounces.

<u>But in the metric world, a number or factor can only be changed decimally. Therefore, it is most important that numerical values for use with SI units are selected with great care to ensure that the chosen numbers have optimum mathematical properties with respect to the needs in their field of application.</u>

The metric measurement world should be regarded as an independent entity to ensure that a "numerical simplicity" is obtained during metrication, which complements and enhances the general advantages of measurement in SI. The review necessitated by the change to new units provides a <u>once-only opportunity</u> to effect simultaneous rationalization at little or no extra cost. To take full advantage of the change, the features of SI, as well as the properties of numbers, must be fully understood.

1.7 Properties of Numbers

The history of mathematics and scientific thought is filled with studies of number systems, number relationships, and number properties. The inherent properties of numbers become an important factor in the selection of numerical values for a metric environment--important because in a coherent decimal measurement system certain numbers are superior to others, and certain number sequences or series provide an "optimum" set of values for requirements or criteria in metric design, production, and construction.

A listing is provided of desirable number features, which should be pursued wherever it is likely that such features will be beneficial in a metric measurement context:

1.7.1 Integers Are Preferred

In general, it is preferable to use integers [whole numbers] wherever practicable, because the sum, the difference, or the product of integers remains an integer. Decimal fractions [decimal parts] often can be turned into integers by the use of a smaller working unit [reference unit]; for example: 0.125 MPa = 125 kPa; 0.35 L = 350 mL.

Conversely, common fractions are avoided where SI units are used, and they should be changed to appropriate numerical equivalents. Common fractions, such as 1/3, or 1/9, should be changed to decimal parts and truncated, as appropriate.

1.7.2 Divisibility and the Usefulness of Composite Numbers

Composite numbers have divisors other than themselves and unity [1]. Composite numbers are most useful where divisibility is required--especially in linear measurement.

All even numbers are divisible by at least the factor 2. In the decimal number system, any number ending in a zero is divisble by at least 10, 5, and 2, in addition to any other factors indicated by the multiplier. Similarly, any number ending in two zeros is divisible by at least 100, 50, 25, 20, 10, 5, 4, and 2, in addition to any other factors indicated by the multiplier.

The numerical significance in terms of "divisibility" is best indicated by "prime factorization," where the number of prime factors indicates the possible range of alternative subdivisions into equal integers. The first number with two different prime factors is <u>6</u> [2 and 3], and the first number with three different prime factors is <u>30</u> [2, 3, and 5]. The useful number <u>12</u> has three prime factors [2, 2, and 3]; and the number <u>60</u> has four prime factors [2, 2, 3, and 5].

The variety of possible divisions into equal parts is directly related to the number and variety of prime factors, as indicated for some of the more significant composite numbers listed below:

Number	Prime Factors	Divisible by
6	2 · 3	2, 3
8	2 · 2 · 2	2, 4
10	2 · 5	2, 5
12	2 · 2 · 3	2, 3, 4, 6
16	2 · 2 · 2 · 2	2, 4, 8
18	2 · 3 · 3	2, 3, 6, 9
20	2 · 2 · 5	2, 4, 5, 10
24	2 · 2 · 2 · 3	2, 3, 4, 6, 8, 12
30	2 · 3 · 5	2, 3, 5, 6, 10, 12, 15
36	2 · 2 · 3 · 3	2, 3, 4, 6, 9, 12, 18
48	2 · 2 · 2 · 2 · 3	2, 3, 4, 6, 8, 12, 16, 24
60	2 · 2 · 3 · 5	2, 3, 4, 5, 6, 10, 12, 15, 20, 30
etc.		

Conversion to the decimally based metric system (SI), however, does <u>not</u> require that all numbers in measurement statements have to be decimal numbers. Optimum workability in technical descriptions and calculations will be obtained by the intelligent combination of three concepts: coherent units, decimal prefixes, and selected preferred numbers.

The selection of composite numbers frequently provides greater facility in calculations or measurement--especially in linear measurement applications in building--and can thus increase efficiency and reduce errors. Due to the coherence of SI units, composite numbers carry over their advantages into derived situations in some applications and, therefore, often expedite or facilitate decision-making.

1.7.3 Numbers in Communication — Some Natural Preferences

To facilitate the adjustments required during the change to metric [SI] units, it is desirable to select numbers which are easily memorized and/or communicated.

The structure of the verbalized number system in the English language is such that the numbers from one to ten, except seven, are single syllable words and, therefore, communicated most easily. Additional words representing contractions are used between ten and twenty, and for all multiples of ten up to ninety. New words are introduced for certain powers of ten: hundred [10^2 or ten times ten]; thousand [10^3 or ten times hundred]; million [10^6 or thousand times thousand], etc.

All verbal expressions of numbers are made by a linear combination of number terms which describes the digits in a number in their order of magnitude; for example, the number symbol <u>425</u> is verbalized as <u>four hundred twenty-five</u>. Above one thousand, and up to one million, the multiplier of the thousands is expressed first, and then the number component smaller than one thousand; for example, the six digit nomeral <u>361 425</u> is verbalized as <u>three hundred sixty-one thousand four hundred twenty-five</u>. This illustrates the merit of the recommended practice for the presentation of numerals with SI, where long numbers are arranged in groups of three numbers from the decimal marker, to facilitate recognition and expression. (Note: Commas are <u>not</u> used with SI to separate thousands, millions, etc., in numbers with more than three digits.) In numbers with decimal parts (decimal fractions), the digits after the decimal marker are expressed as a sequence of number words; for example, <u>361.425</u> is verbalized as <u>three hundred sixty-one point four two five</u>.

The comparison of number symbols and verbalized numbers clearly demonstrates the greater simplicity of communication by means of number symbols.

<u>There is a natural preference for those numbers which have compact number words, because they are more easily memorized and accurately communicated in speech</u>.

For example: A single word such as eighty (80) is preferable to combinations such as seventy-nine (79) or eighty-one (81); similarly, six hundred (600) is superior in communication to six hundred and nine (609).

1.7.4 Selection of Numbers from Preferred Number Series

Where a range of requirements or criteria needs to be expressed by a set of discrete numerical values, the optimum sequence or progression generally is obtained with the use of a "preferred number series," discussed in more detail in Section 2.5.

Two broad groups of number series can be distinguished:

[a] <u>arithmetic series</u>, which have a regular [constant] interval between successive terms (e.g. 2, 4, 6, 8,....), or an irregular interval determined by a specific arithmetic formula (e.g. the Fibonacci series: 0, 1, 1, 2, 3, 5, 8, 13,....); and

[b] <u>geometric series</u>, which have a constant ratio [multiplier factor] between successive terms (e.g. 1, 2, 4, 8, 16,....), although such a ratio does not need to be a whole number.

An understanding of preferred number series is <u>most important</u> in the investigation and selection of numerical values for use in a metric environment, as many situations will arise where the adoption of a particular series of numbers provides the "optimum" selection of values in a given working range.

Furthermore, there will be instances where a singular [independent] value may subsequently become part of a series of values. The initial selection of a numerical value which is part of a preferred number series is bound to facilitate its integration into an eventual set of preferred values.

Preferred number series are discussed in detail in Part 2.

1.7.5 Compatibility of Numerical Values with Values in International Standards

Where the selection of numerical values for use with SI units has international significance, relevant international standards should be examined to ascertain whether compatible or identical values can be chosen during the change to SI to replace customary requirements. In 1956, the Council of the International Organization for Standardization [ISO] resolved that the Renard series of preferred numbers should be used for international standardization, wherever practicable.

1.8 Conversion of Numerical Values

Metric conversion--or metrication--is the process of change to a new set of reference units. This automatically involves a change in numerical values by the ratio between customary and metric reference units--this ratio being known as the "conversion factor." The conversion factor generally is a complex number, often with many places of decimals, due to the differi origin of the metric and customary reference units. There will be very few situations where a conversion yields a whole number [an integer], and only on rare occasions will such a whol number be a preferred number.

Conversions to integers occur at intervals in the conversion of temperature values from the Fahrenheit scale to the Celsius scale: 32°F equals 0°C exactly, and 212°F equals 100°C exactly--therefore, by definition, every increment of 9°F yields an increment of 5°C; for example: 41°F = 5°C; 50°F = 10°C; 59°F = 15°C; 68°F = 20°C; 77°F = 25°C; 86°F = 30°C, etc. Both scales achieve numerical equality at -40 degrees [-40°F = -40°C].

The redefinition of the yard-meter relationship in 1959 resulted in: 1 yd = 0.9144 m exactly and 1 inch = 25.4 mm exactly. Therefore, all multiples of 5 inches will yield integers in millimeters; for example: 5" = 127 mm, 10" = 254 mm, 15" = 381 mm, 20" = 508 mm, etc. Although the "exact conversion" results in whole numbers, they are not "preferred numbers."

In general, where physical properties or sizes of products are unchanged, the change to met [SI] measurement units will result in numbers with decimal parts, and some degree of truncation, rounding, or rationalization is desirable. Where it is possible to adjust physical properties or sizes of products, it is advantageous to select preferred numerical values fo metric products.

Four types of conversion activity can be distinguished:

1.8.1 Exact Conversion (No Change)

An "exact conversion" [or direct conversion] denotes a <u>precise</u> conversion from a custom value to the "exact equivalent" in SI units, generally expressed to a number of places c decimals to satisfy scientific, legal, or statistical requirements. For example, in an exact conversion, 1 pound (av.) is equal to 0.453 592 37 kg. Obviously, this kind of pr cision can only be obtained in a scientific laboratory.

Exact conversions are needed where interchangeability of mechanical parts is required. But high precision is seldom required in building design and construction, so that exact conversions should be avoided as they provide unnecessarily cumbersome values.

1.8.2 Soft Conversion (Minimal Changes within Tolerances only)

A "soft conversion" represents a change in the units used for description, but normally no change in a material, product, or requirement, or only a minimal change within existi tolerances. A soft conversion implies that the change is one made on paper only--or in the software--thus the name.

In soft conversions, the exact conversion is generally rounded to the nearest integer or sensible number (within applicable tolerances), but normally <u>not</u> to a preferred number. For example, a length of 16 feet is converted to 4875 mm or 4880 mm from the exact equivalent of 4876.8 mm, rather than to 4800 mm or 4900 mm, which are modular preferences. Similarly, 10 psi becomes 69 kPa by rounding from 68.9476 kPa, rather than 70 kPa.

It is recommended that soft conversions be limited in specifications, standards, codes, or other technical data, because their use simply leads to a perpetuation of customary practices with a "metric veneer," with none of the advantages that are expected to flow from the use of preferred values and rationalization.

1.8.3 Hard Conversion (Change to New Values)

A "hard conversion" represents a definite change from an existing physical size or magnitude to a different, new, and "preferred" metric [SI] value. A hard conversion--which indicates a change in the "hardware" as well as the software--will normally lead to incompatibility between customary and metric properties or product characteristics. For example, a 1 gallon container is replaced by a 4-liter container [a 5.7% increase]; a length of 12 feet is replaced by a "preferred" metric length of 3600 mm [a 1.6% decrease].

The hard conversion is preferred in metrication, although it is more difficult to effect because it generally requires a modification in design detailing, production processes, and/or assembly operations. As in countries with fully developed metric systems, it is anticipated that U.S. decisions on final metric values will lead to simple integer numbers and preferred values in SI units.

1.8.4 Rationalization (Development of an Optimum Functional Range)

It is certain that the term "rationalization" of requirements, products, or sizes will be encountered during the change to SI. Rationalization is a "by-product" of metrication, where the opportunity for review and change is taken to implement positive changes in addition to conversion activities.

Rationalization means the establishment of an optimum functional range at the time of the transition to metric products or requirements, and the introduction of new values that have been indicated as a result of experience, research, or development--thus combining two otherwise separate changes. Rationalization proposals are especially valuable in relation to factors, such as design data, which require periodic functional review and re-evaluation.

Other examples of "rationalization through metrication" are:

[a] variety reduction in the products sector, by the following means
  - i. substitution of preferred metric products comprising a smaller range
  - ii. deletion from the product line during hard conversion or soft conversion
  - iii. specialization in the most functionally efficient or cost-effective segment of a product range;

[b] harmonization and unification of different, differing, or conflicting technical data, standards, or codes, where the substitution of a singular value or a number of preferred values is feasible and/or desirable;

[c] simplification of practices, procedures, and processes through less complicated numerical description.

There are many examples of rationalization from other countries engaged in metrication. The study and evaluation of precedent can provide useful guidance as to the areas where special effort is most likely to be rewarded by more rational and improved solutions.

1.9 Alternative Approaches to Metrication

There are two basic approaches to metrication of technical information for use in construction and engineering:

[1] a restricted approach, in which existing products, requirements, or data are converted, and customary values used for guidance in "value analysis" to determine the extent of change that is possible, practicable, or permissible; and

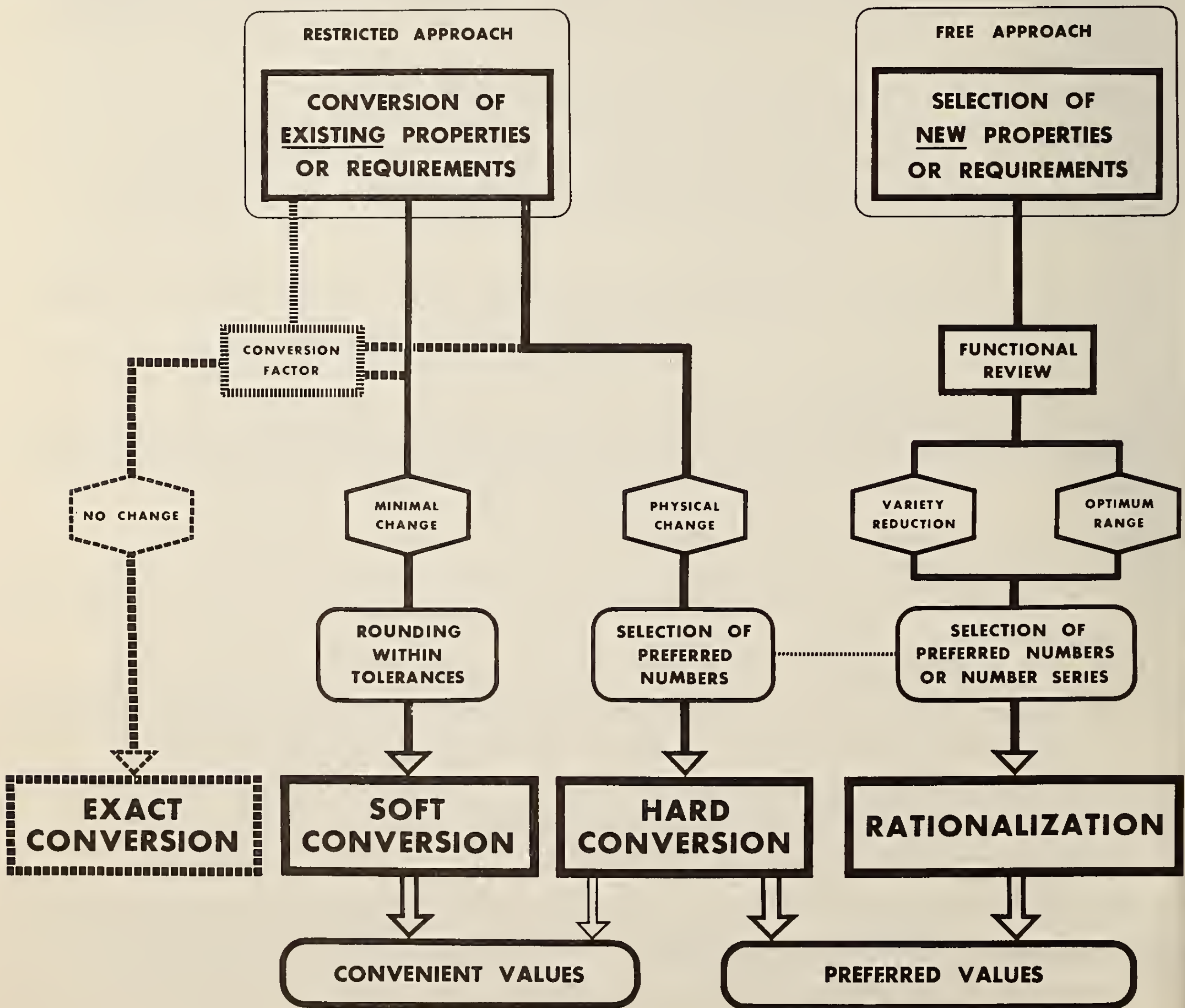
[2] a free approach, leading to the development of entirely new and rationalized product ranges, requirements, or technical data, in which there is little or no restriction on the selection of new values.

In the restricted approach, three types of conversion can be distinguished, leading from the exact conversion, through a soft conversion, to a hard conversion. The hard conversion provides the link to the free approach--also designated as rationalization--because both rely on preferred numerical values for use with SI.

In the free approach to metrication--or rationalization--optimum new values are determined on the basis of performance requirements. The free approach requires a "commitment to change," rather than the acceptance of a "mere conversion" of existing requirements.

The sequences and relationships of alternative metrication strategies for technical information are illustrated in Figure 1. The objective in conversion or rationalization should be to make a change to either "convenient values" or "preferred values." Convenient values are values in which the number is selected primarily for its simplicity and/or convenience in description and practical use. Preferred values are values in which the number is selected on the basis of its membership in a family of numbers that are preferred for functional or mathematical reasons. In general, convenient values are best suited to applications involving "individual values," while preferred values are mainly associated with applications involving "sets or series of values."

Figure 1 STRATEGIES FOR CONVERSION AND RATIONALIZATION



PART 2: PREFERRED NUMBER CONCEPTS FOR INDIVIDUAL VALUES AND SERIES OF VALUES.

2.1 General

Certain numbers are more effective when used in conjunction with SI units, because they will simplify descriptions, calculations, and/or measurement verification. It is the objective of this Part to assess various concepts of "convenient numbers" and "preferred numbers," and their application, especially in conversion decisions during the change from customary values to SI values.

In any measurement statement, the "number" always indicates the magnitude of the stated value relative to the reference unit for the physical quantity involved; for example, a mass of 10 kilograms simply means a mass ten times that of the reference unit, the kilogram. The number always remains a multiplier [or factor], but becomes the key element in mathematical processes, such as addition, subtraction, multiplication and division. The significance of the number is further enhanced in SI, because there is a one-to-one [or unity] relationship between all reference units for physical quantities in the system. This means that a number associated with a reference unit will generally remain in calculations involving other or derived units. The use of preferred prefixes representing ternary powers of ten makes it possible to avoid very small or excessively large numbers in numerical values. However, the use of a different prefix for an SI unit will not alter the sequence of numerals in a number; it will only change their position relative to the decimal marker.

Compared with numerical values expressed in customary units, numerical values in SI must rely on the number to provide facility in calculations or measurement applications; no longer will a numerical value have any "inbuilt" non-decimal factors [such as 3, 4, 6, 8, 9, 12, 16, etc.] between successive measurement units for the same physical quantity. If divisibility by 12 is considered necessary, then the number in the SI expression must be divisible by 12! In the metric world, a poor choice of number can never be improved simply by changing the working unit; because there is only one unit for any physical quantity a number that has been selected for use with SI can only be changed decimally by using a different prefix.

2.2 Numerical Values in Measurement Applications

For the purpose of conversion and rationalization of numerical values, three types of value can be distinguished in measurement applications:

[i] Individual Values

Individual values are numerical values which appear on their own and specify a "singular" and nominally independent measurement or phenomenon.

[ii] Individual Values Which May Be Part of a Set or Series of Values

While some individual values appear on their own in technical information, they may be part of, or subsequently become part of, a set or series of preferred values. This frequently is the case with specified linear dimensions, which are actually part of a set of preferred dimensions. A knowledge of preferred values is needed to select the most appropriate metric replacement for a customary value.

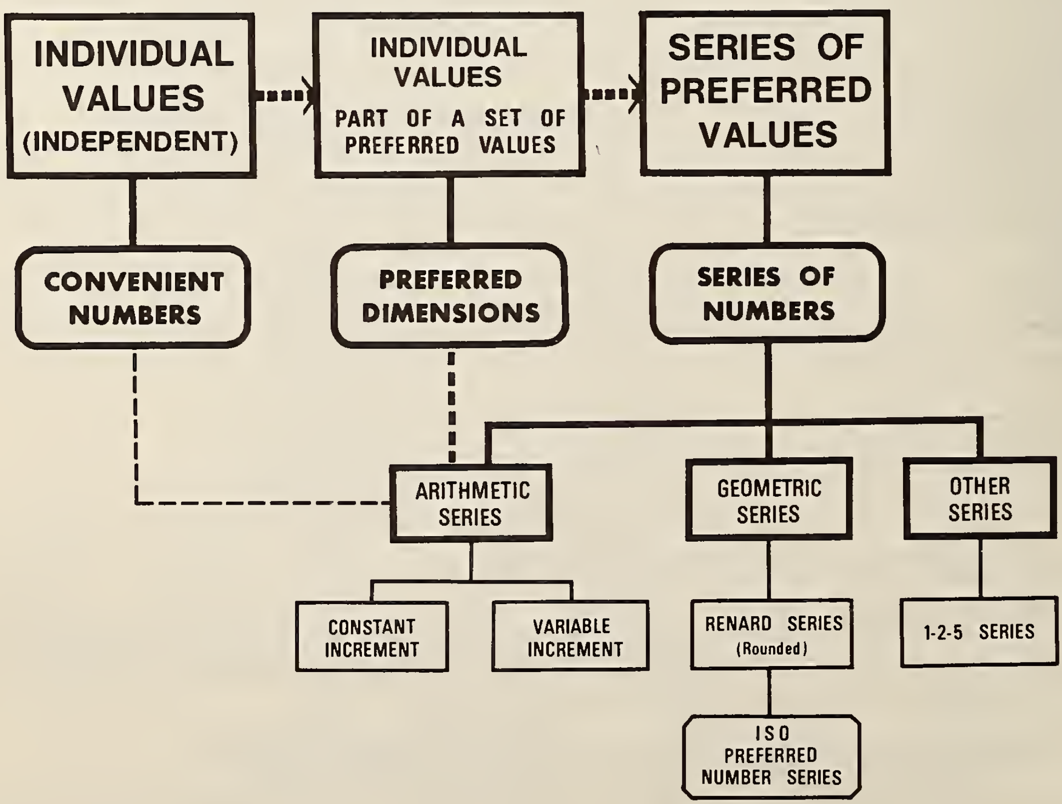
[iii] <u>Series of Preferred Values</u>

Series of preferred values are groups or sequences of numerical values which are related by a specific mathematical or other relationship, and feature series of preferred or of selected numbers.

Series of preferred values are found in product catalogs, coinage, size or grade tables, and other ranges of functional characteristics. Preferred number series are valuable in standardization, rationalization, and size selection, because they ensure a functional progression within a given or proposed range of requirements.

The relationship of individual values and series of values to various number preferences is illustrated in Figure 2. Convenient numbers are normally linked with independent individual values, and they are discussed in Section 2.3. Preferred linear dimensions form a specfic set of preferences, and they are discussed in Section 2.4. Various series of numbers and their properties are discussed in Section 2.5 and following Sections.

Figure 2 VARIOUS NUMBER PREFERENCES FOR USE IN METRIC CONVERSION AND RATIONALIZATION



2.3 Convenient Numbers

There are many applications in specifications, standards, codes, and other technical data, where a convenient numerical value provides the best recognition point or measurement value.

Basically, integers are more convenient than expressions which include decimal parts [decimal fractions]. Furthermore, where measuring devices are used, values which represent numbered subdivisions on such instruments are more useful than values which have to be interpolated. For example, where a tape or a scale is graduated in intervals of 5, any value that represents a multiple of 5 is more "convenient" to measure or verify than one which is not.

In addition, where operations involve the subdivision of quantities into two or more equal parts, any number that is highly divisible has an explicit advantage.

The following concept of "convenient numbers" for the conversion or development of specifications, standards, codes, and technical information has been developed to supplement preferred numbers in such situations where a convenient number is quite adequate or more appropriate. Convenient numbers are useful in the selection of numerical values for many aspects of linear measurement other than coordinated dimensions, and in the measurement of mass, capacity, time, temperature, or other quantities that do not include a power in the measurement unit [as do area, volume, force, pressure, stress, energy, work, heat, power, electrical potential, illuminance, etc.].

The system of convenient numbers for metric values is based on assigned preferences for those numbers which are multiples of 5, 2, and 1--and their powers of ten--in a descending order. The system is an extension of the 1-2-5 concept in reverse, as it includes multiples as well. Linear dimensions above 100 mm are specifically excluded, as they are subject to a different system of numerical preference.

Table 1, shown below, indicates the mathematical construction of a preference system for convenient numbers in the range 0.1 to 10 000; and Table 2, on page 18, provides a complete listing of all convenient values in the range 10 to 100.

Table 1 A PREFERENCE SYSTEM FOR CONVENIENT NUMBERS

Numerical Range	Numerical Preference						
	1st	2nd	3rd	4th	5th	6th	7th
0.1 to 1.0	*n* x 0.5	*n* x 0.2	*n* x 0.1	*n* x 0.05	*n* x 0.02	*n* x 0.01	
1 to 10	*n* x 5	*n* x 2	*n* x 1	*n* x 0.5	*n* x 0.2	*n* x 0.1	
10 to 100	*n* x 50	*n* x 20	*n* x 10	*n* x 5	*n* x 2	*n* x 1	
100 to 1000	*n* x 500	*n* x 200	*n* x 100	*n* x 50	*n* x 20	*n* x 10	*n* x 5
1000 to 10 000	*n* x 5000	*n* x 2000	*n* x 1000	*n* x 500	*n* x 200	*n* x 100	*n* x 50

Notes:
1. *The symbol "n" represents "all multiples of the associated number" within the specified numerical range.*
2. *In certain contexts, n x 25, n x 250, and n x 2500, may be substituted as second preferences for n x 20, n x 200, and n x 2000.*

Table 2 SCHEDULE OF CONVENIENT NUMBERS BETWEEN 10 AND 100

1st Preference n x 50	2nd Preference n x 20	3rd Preference n x 10	4th Preference n x 5	5th Preference n x 2	6th Preference n x 1
		10			
					11
				12	
					13
				14	
			15		
				16	
					17
				[illegible]	
					19
	20				
					21
				22	
					23
				24	
			25*		
				26	
					27
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					29
		30			
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				68	
					69
		70			
					71
				72	
					73
				74	
			75*		
				76	
					77
				78	
					79
	80				
					81
				82	
					83
				84	
			85		
				86	
					87
				88	
					89
		90			
					91
				92	
					93
				94	
			95		
				96	
					97
				98	
					99
100					

Notes:

1. *Numbers are shown once only, in the highest applicable preference column. (For example: The number 20 would occur as 3rd, 4th, 5th, and 6th preference as well as 2nd preference).*
2. *In some contexts, 25 and 75 may become 2nd preferences rather than 4th preferences.*

In the practical application of a "convenient numbers approach" to the selection of suitable metric values, it is desirable to start with the highest possible preference and then to gradually refine the difference until an acceptable and convenient metric value has been found.

This approach is illustrated by means of a practical example.

Example USE OF "CONVENIENT NUMBER PREFERENCES" TO SELECT A METRIC VALUE

The direct conversion of a force of 21 kips (21 000 pounds-force) yields a metric value of 93.413 kN (kilonewtons). Because the value is not part of a set or series, the preference system for convenient values is a suitable base for the selection of a metric replacement force with a simple numerical value.

The following alternatives are selected from Table 2 [Preferences in range 10 - 100]:

PREFERENCE	VALUE	% CHANGE	REVERSE CONVERSION	CONSIDERATIONS AND COMMENTS
First [*n* x 50]	100	+ 7.05	22.48 kips	100 is a preferred number, divisible by 2, 4, 5, 10, 20, 25, and 50.
Second [*n* x 20]	100	+ 7.05	22.48 kips	as above
Third [*n* x 10]	90	- 3.65	20.23 kips	90 is a convenient number, divisible by 2, 3, 5, 6, 9, 10, 15, 18, 30, and 45.
Fourth [*n* x 5]	95	+ 1.70	21.36 kips	95 is divisible by 5 and 19 only.
Fifth [*n* x 2]	94	+ 0.63	21.13 kips	94 is divisible by 2 and 47 only.
Sixth [*n* x 1]	93	- 0.44	20.91 kips	93 is divisible by 3 and 31 only.

The important aspect in this approach to the ranking of alternatives is that it starts with the most preferred value. The percentage change is reduced gradually to a narrow margin, approaching a "soft conversion" of 93.4. In the example, the value 93 varies by only 0.44% from the original value, and the value of 94 by only 0.63%.

Additional considerations can be built into the selection process; for example, where divisibility is useful or required, a value of 96 may come into contention, because it can be divided by 2, 3, 4, 6, 8, 12, 16, 24, 32, and 48.

If a requirement exists that the customary value must form either a "minimum" or a "maximum" during the selection of a metric value, then the alternatives can be shown in two groups: those that have a positive variance, and those that have a negative one.

Another approach to the selection of convenient numbers involves the use of a decision matrix which shows the best alternative for various permissible percentage changes:

PERMISSIBLE VARIANCE	+ and -	+ only	- only
10% max.	100	100	--
5% max.	90	95	90
2% max.	95	95	93
1% max.	94	94	93

All decision options are shown unambiguously. It is also possible to select additional or alternative permissible variances, and it is very simple for a computer to produce the decision table.

2.4 Preferred Sets of Values -- Preferred Dimensions for Use in Building

2.4.1 Overview

In design, production, and construction, the majority of all measurement statements involves linear measurement, in the form of requirements for length, width, height, depth, thickness, diameter, circumference, etc. Frequently, such measurement statements are part of a set or sequence of values and, therefore, not independent. To select the most appropriate metric values during conversion of linear dimensions, it is desirable to appreciate the concept of "dimensional coordination," which involves special dimensional preferences for buildings and building products. In metric dimensional coordination, a common set of preferred values [or preferred dimensions] is used to establish the geometry of buildings as well as the sizes of constituent components or assemblies. All preferred dimensions are related to a "building module;" therefore, the term "modular coordination" is sometimes substituted.

In the metric building world, the fundamental unit of size in the system of coordination is the "basic module" of 100 mm. This basic [metric] module is also designated by the symbol M. It is slightly less in length than the 4-inch [101.6 mm] module which has been used in the United States, and should not be equated with this customary module, as metric modular product dimensions will be 1.6 percent shorter.

The metric module of 100 mm has already been endorsed as the basic unit of size in "metric dimensional coordination" in the United States by various industry groups, such as Committee E-6, Performance of Building Constructions, of the American Society for Testing and Materials, the Construction Industries Coordinating Committee [CICC] and a number of its Sector Committees in the American National Metric Council, and the Metrication and Dimensional Coordination Task Force of the American Institute of Architects. Preferred dimensions of buildings and preferred sizes of building components should be whole multiples of the metric module, where-ever practicable. The relationship then becomes mutually reinforcing: preferred sizes can be used to the greatest advantage in buildings set out to preferred dimensions; and the design of buildings in preferred dimensions will encourage the procurement and use of building products in preferred metric sizes. Building products vary from small components placed in situ by hand and ranging in size up to about 1200 mm [12M], to larger elements placed by mechanical means which may range up to 12 000 mm [120M]. Building dimensions vary from small thicknesses of structural elements and dimensions of small spaces to very large spaces with dimensions of 60 000 mm [600M] or more in special structures. To ensure optimum utilization of materials, preferred dimensions play an important part in design, production, and construction.

This Section deals with numerical considerations in the determination of preferred dimensions and sizes under three categories:

[a] Preferred multimodular dimensions, which are selected multiples of the basic module;

[b] Inframodular sizes, which are selected dimensions smaller than the basic module; and,

[c] Intermodular sizes, which are dimensions larger than 100 mm, but not a whole multiple of the basic module.

It is important to appreciate that "preferred dimensions" in the context of metric dimensional coordination are "reference dimensions" or "ideal dimensions," rather than actual dimensions. Allowances for joints, tolerances, and deviations are taken into account in the determination of actual dimensions. For example, while a component may be described by a preferred size of 400 mm [4M], this dimension will include an allowance for half a joint width on either side of the component, and the "actual dimension" will be less to ensure fit in a coordinating space. If the design joint thickness is 10 mm, the dimension for use as "manufacturing target dimension" will be 390 mm.

2.4.2 Preferred Multimodular Dimensions

A judicious selection of multimodular preferences is required, because the acceptance of all multiples of 100 mm [M] as preferences would lead to an excessively large variety of choices and would militate against standardization and variety reduction.

Due to the nature of the construction process, which involves the joining of many individual and, frequently, repetitive components, assemblies, or elements into an organized whole, those building dimensions which are a highly "divisible" multiple of the basic module are superior to those which are a prime number multiple. Thus, the first selection process for preferred multimodular dimensions involves the choice of composite numbers with the largest number of prime factors, as this will allow the widest range of combinations of units to exactly match the preferred dimension. Most small multimodular building components, such as bricks, tiles, blocks, and panels, will have basic sizes of 200 mm [2M], 300 mm [3M], 400 mm [4M], and 600 mm [6M], due to technical as well as historical factors. This means that any multiple of 100 mm [M], which includes as factors the numbers 2, 3, 4, and/or 6, will immediately become a strong preference because the variety of design options is greatly increased.

Divisibility of selected preferred values up to 6000 mm [60M] into "modular factors" is shown in Table 3.

Table 3 DIVISIBILTY OF PREFERRED DIMENSIONS INTO MODULAR FACTORS

PREFERRED VALUE	DIVISIBILITY INTO MODULAR FACTORS [Sizes up to 3000 mm]	NUMBER OF OPTIONS
600 mm [6M]	100, 200, 300, 600	4
800 mm [8M]	100, 200, 400, 800	4
1200 mm [12M]	100, 200, 300, 400, 600, 1200	6
1800 mm [18M]	100, 200, 300, 600, 900, 1800	6
2000 mm [20M]	100, 200, 400, 500, 1000, 2000	6
2400 mm [24M]	100, 200, 300, 400, 600, 800, 1200, 2400	8
3000 mm [30M]	100, 200, 300, 500, 600, 1000, 1500, 3000	8
3600 mm [36M]	100, 200, 300, 400, 600, 900, 1200, 1800	8
4000 mm [40M]	100, 200, 400, 500, 800, 1000, 2000	7
4800 mm [48M]	100, 200, 300, 400, 600, 800, 1200, 1600, 2400	9
5400 mm [54M]	100, 200, 300, 600, 900, 1800, 2700	7
6000 mm [60M]	100, 200, 300, 400, 500, 600, 1000, 1200, 1500, 2000, 3000	11

Table 3 clearly shows that dimensions, in which 600 mm [6M], 1200 mm [12M], or 6000 mm [60M] are a factor, will be highly divisible and, therefore, preferred in a dimensionally coordinated building environment. The choice of dimensions divisible by 600 mm [6M] and whole multiples thereof will provide the designer with a more useful set of factors in planning and detailing decisions than would the choice of dimensions divisible by 500 [5M] or 1000 mm [10M] which, superficially, may appear to yield useful values, especially since 500 and 1000 would otherwise be preferred numbers for use with SI. [For many years, German building design and product sizing were based on an octametric module of 125 mm, with values of 125 mm, 250 mm, 375 mm, 500 mm, 750 mm, 1000 mm, 1250 mm, etc., featured prominently in building dimensions. However, this selection was found to create many problems at the submodular level. The octametric system has been superseded in Europe by the acceptance of the international building module, 100 mm, and its preferred multiples which contain as factors the numbers 2, 3, and 6.]

The dimension of 6000 mm [60M] provides a "supermodule," on which larger building dimensions can be based to ensure that the maximum amount of factorization is obtained.

As a general rule, and based upon the concept of "divisibility," all multiples of the basic module over 5 which are a prime number [e.g., 7, 11, 13, 17, 19, 23, 29, 31, etc.] are least preferred and should be avoided as controlling dimensions unless they represent the only modular option for functional or economic reasons.

At the international level, and in many national standards, a distinction is made between multimodular dimensions for horizontal applications and for vertical applications. This distinction is due to the fact that horizontal dimensions of spaces are generally larger than vertical dimensions and, therefore, benefit from the utilization of a larger modular increment in the planning module. For the purposes of this discussion it should be recognized that dimensional preferences often need to be further refined according to specific applications or the direction of application.

Numerical preference in dimensions can be best illustrated by means of an example. Where the designer has a free choice of dimension in the range 4700 mm [47M] to 5000 mm [50M], he can list his decision options to utilize whole components of modular sizes as follows:

i.	<u>4700 mm</u>	2 options	100 mm, 4700 mm
ii.	<u>4800 mm</u>	10 options	100 mm, 200 mm, 300 mm, 400 mm, 600 mm, 800 mm, 1200 mm, 1600 mm, 2400 mm, and 4800 mm
iii.	<u>4900 mm</u>	3 options	100 mm, 700 mm, 4900 mm
iv.	<u>5000 mm</u>	6 options	100 mm, 200 mm, 500 mm, 1000 mm, 2500 mm, 5000 mm

The optimum decision alternative is immediately apparent: namely, 4800 mm. This alternative offers 10 possibilities to utilize whole multimodular or modular components, most of which, in turn, are themselves preferred dimensions.

Based upon the principles outlined, a "<u>set of preferred values</u>" for use in building geometry and building product sizes can be developed, with preferences to distinguish the most useful alternatives. The construction of such a preference system for dimensions above 600 mm [6M] is detailed on page 23, in Tables 4 and 5.

Up to 600 mm, all multiples of 100 mm constitute preferences. Above 600 mm, multimodular preferences are shown in three dimensional ranges:

A. 600 mm to 3600 mm B. 3600 mm to 12 000 mm C. Dimensions over 12 000 mm

Three preference categories only are shown in Table 4: 1 [First Preference]; 2 [Second Preference]; and, 3 [Third Preference].

Table 4 MATRIX OF CRITERIA FOR THE ALLOCATION OF DIMENSIONAL PREFERENCES IN BUILDING

[All values are in millimeters, and represent multiples of the international building module of 100 mm.]

RANGE [mm]	1 FIRST PREFERENCE	2 SECOND PREFERENCE	3 THIRD PREFERENCE
A 600 - 3600	All multiples of 600	All multiples of 300 and 400, not included in A.1	All multiples of 100, not included in A.1 and A.2
B 3600 - 12 000	All multiples of 1200	All multiples of 600, not included in B.1	All multiples [except primes] of 300 and 400, not included in B.1/B.2
C Above 12 000	All multiples of 3000	All multiples of 1200, not included in C.1	All multiples of 600 and 1500, not included in C.1 and C.2

The suggested preferred multimodular dimensions for use in the coordination of sizes in building design and production in the range 600 mm to 12 000 mm are listed in Table 5.

Table 5 PREFERRED MULTIMODULAR DIMENSIONS FROM 600 mm TO 12 000 mm [in millimeters]

FIRST PREFERENCE	SECOND PREFERENCE	THIRD PREFERENCE	
600	800	700	4000
1200	900	1000	4500
1800	1500	1100	5600
2400	1600	1300	6300
3000	2000	1400	6400
3600	2100	1700	7500
4800	2700	1900	8000
6000	2800	2200	8100
7200	3200	2300	8800
8400	3300	2500	9900
9600	4200	2600	10 000
10 800	5400	2900	10 400
12 000	6600	3100	10 500
	7800	3400	11 200
	9000	3500	11 700
	10 200		
	11 400		

It is recommended that where metric values are required for linear dimensions in building or engineering specifications, standards, and codes, they be selected from Table 5. In certain circumstances, especially where repetitive sizing is involved, additional dimensions may be required. It is recommended that where such additional dimensions above 3600 mm are required, multiples of 400 mm, 300 mm, and 200 mm be tried in descending order, before any others.

2.4.3 Preferred Inframodular and Intermodular Dimensions

Practical considerations in building design and construction dictate the use of "non-modular" dimensions--that is, values other than whole multiples of 100 mm [M]--especially, where sizes are determined by functional and/or economic factors rather than numerical preference. Such items indicate component thickness, wall thickness, floor thickness, and dimensions of elements, assemblies, or components (which are not required to be dimensionally coordinated.)

Preferred <u>inframodular dimensions</u> are selected values smaller than the basic module of 100 mm, but having a direct relationship to the module and resulting in a whole number.

Preferred <u>intermodular dimensions</u> are selected dimensions larger than 100 mm, but falling in between whole multiples of the module.

The judicious selection of inframodular and intermodular dimensions together with multimodular sizes can often preserve modularity in the reference system. For example, the choice of two 50 mm [$\frac{M}{2}$] partitions on either side of a multimodular space will ensure that an overall multimodular dimension is obtained, and that the option exists of selecting either the internal or the external dimension from a table of preferred multimodular dimensions. Similarly, the use of a floor zone of 150 mm [$\frac{3M}{2}$] or 250 mm [$\frac{5M}{2}$] may be required for functional or economic reasons; and, in combination with a multimodular room height, the use of a half-modular zone will at least ensure that every second story will coincide with a multimodular dimension.

[a] <u>Inframodular Dimensions</u>

The following inframodular dimensions are preferred due to their direct relationship to the basic module and preferred multimodules:

1. <u>50 mm</u> [$\frac{M}{2}$]
2. <u>25 mm</u> [$\frac{M}{4}$]; 75 mm [$\frac{3M}{4}$]
3. <u>20 mm</u> [$\frac{M}{5}$]; 40 mm [$\frac{2M}{5}$]; 60 mm [$\frac{3M}{5}$]; 80 mm [$\frac{4M}{5}$]
4. <u>10 mm</u> [$\frac{M}{10}$]; 30 mm [$\frac{3M}{10}$]; 70 mm [$\frac{7M}{10}$]; 90 mm [$\frac{9M}{10}$]

These preferences, with the exception of the second preferences of 25 mm and 75 mm--which have been established internationally--are directly related to the concept of convenient numbers in the range 10 to 100.

[b] <u>Intermodular Dimensions</u>

Although intermodular dimensions should be limited as far as practicable, there will be instances where such sizes are necessary, desirable, or unavoidable in the context of metric dimensional coordination. The most preferred intermodular sizes are those, which in combination of two, four, or five, yield a preferred multimodular size.

It is recommended that the following intermodular preferences be selected where required:

1. First preference: n x 50 mm: 150, 250, 350, 450,.....
2. Second preference: n x 25 mm: 125, 175, 225, 275,.....
3. Third preference: n x 20 mm: 120, 140, 160, 180,.....

Multiples of 50 mm are particularly useful where "doubling" is involved that will bring the sum of two intermodular dimensions back to a multimodular dimension. A typical example in building is the half-landing height in a stairway with a floor-to-floor height of, say, 2700 mm, which is 1350 mm from each floor level.

Where three components are used to combine to a preferred multimodular size that is not divisible by 3, such as 400 mm or 800 mm, the non-integral numbers $\frac{400}{3}$ and $\frac{800}{3}$ for the format size [component plus half a joint width on each side] should be rounded to 133 mm and 267 mm, respectively.

2.4.4 Selection Matrix for Preferred Linear Dimensions in Building

As a further refinement of the preferred value selections indicated in Sections 2.4.2 and 2.4.3, it is possible to establish a matrix of preferences for rationalized linear dimensions in building, using five dimensional ranges with five preferences each, as shown in Table 6:

Table 6 SELECTION MATRIX FOR PREFERRED METRIC DIMENSIONS

DIMENSIONAL RANGE [mm]	1st PREFERENCE	2nd PREFERENCE	3rd PREFERENCE	4th PREFERENCE	5th PREFERENCE
0 - 100	n x 50	n x 25	n x 20	n x 10	n x 5
100 - 600	n x 100	n x 50	n x 25	n x 20	n x 10
600 - 3600	n x 600	n x 400 n x 300	n x 100	n x 50	n x 25
3600 - 12 000	n x 1200	n x 600	n x 400 n x 300	n x 100	n x 50
Above 12 000	n x 3000	n x 1200	n x 600 n x 1500	n x 400 n x 300	n x 100

Note: Where alternative preferences are shown, selections should be based on compatibility with dominant component sizes; for example, where it is expected that component sizes of 400 mm or integral multiples of 400 mm will predominate, n x 400 is obviously a better preference than n x 300.

In all cases, n represents a whole number multiple of the metric value shown. Multiples where n is a prime number are least preferred.

Table 6 can be used in automated selection of possible metric values in conversion situations. The application of such a selection process is illustrated by means of the example below.

An exact conversion of a customary reference value is 5791 mm. The use of the fourth row in Table 6 yields the following hierarchy of preferences:

First preference:	n x 1200 mm	Nearest multiple:	6000 mm	[+3.6%]
Second preference:	n x 600 mm		6000 mm	[+3.6%]
Third preference:	n x 400 mm		5600 mm	[-3.3%]
	n x 300 mm		5700 mm	[-1.6%]
Fourth preference:	n x 100 mm		5800 mm	[+0.2%]
			5900 mm	[+1.9%]
Fifth preference:	x 50 mm		5750 mm	[-0.7%]

While 6000 mm clearly dominates the alternatives as both first and second preference, 5700 mm, 5800 mm, or 5900 mm would be acceptable if the maximum variance has to be less than two percent.

2.4.5 The Effect of Changes in Length on Area, Volume, or Other Section Properties

In some instances, it will be necessary to consider the effect of dimensional changes in linear measurement on area, volume, or other geometrical section properties. (While a change from 4 inches to 100 millimeters represents a reduction in length of only 1.6%, the change from a 4-inch square to a 100-millimeter square represents a reduction in area of 3.1%; and the change from a 4-inch cube to a 100-millimeter cube [or a liter] represents a reduction in volume of 4.7%.)

These reductions may be significant in relation to structural, mechanical, or energy considerations. For example, a metric modular space of 3600 mm x 3000 mm x 2400 mm is almost 5 percent smaller than an equivalent customary modular space of 12' x 10' x 8' and, therefore, requires less heating or cooling to obtain desirable comfort levels.

2.4.6 Large Non-building Dimensions

Where the rationalization is required of large non-building dimensions, such as in site layouts, roadworks, pipe systems, etc., such dimensions may be more appropriately expressed in meters, with dimensional preferences chosen from values in Section 2.3 "Convenient Numbers."

2.4.7 Preferred Sizes (Linear Dimensions) for Use in Engineering Design

The majority of dimensions for the detailed design of metric equipment or components used in engineering occurs below 300 mm. Preferred dimensions for use in building do not provide an adequate variety of sizes for engineering design, and it has been found necessary in Britain, Australia, and a number of other countries to develop a set of preferences to assist in variety reduction and rationalization of sizes. Preferred values from geometric number series form a useful starting point for preferred sizes in engineering but lack the required small increments at the upper end of a range and contain some unduly awkward numbers.

Section 2.5.11, page 35, and Appendix C, page 72, deal with preferred sizes [linear dimensions] for engineering purposes based on first, second, and third choices of dimensions. The main difference between preferred sizes for engineering and preferred dimensions for building is that for dimensions above 100 mm the multiples of 25 mm are accorded a much higher preference in building than in engineering design applications.

2.4.8 Standards for Preferred Metric Dimensions and Sizes in Building

It is expected that a series of ASTM standards dealing with "Metric Dimensional Coordination in Building Design and Production" will be prepared under the auspices of ASTM Committee E-6, Performance of Building Constructions. Such standards will be developed specifically in metric terms <u>only</u>, and they should provide guidance on the choice of the most appropriate linear dimensions for use by the construction community during the transition to a preferred metric [SI] dimensional environment. It is important that any metric technical data prepared in the interim will not inhibit, but rather reinforce, a move to a preferred and coordinated dimensional framework for buildings, as well as building products.

2.5 Series of Preferred Values -- Series of Numbers for Use with SI

2.5.1 Overview

Three general groups of number series can be distinguished: arithmetic series of numbers, geometric series of numbers, and special purpose series with irregular steps between successive terms in the series. Number series are important where a range of criteria is to be expressed by an effective selection of values, so that successive values have a functional relationship. Because of the opportunities they provide for standardization and rationalization activity which ought to accompany the change to the modern metric system, number series take on particular importance in the change to metric measurement.

There has been considerable international work dealing with the identification and assignment of preferences in number series, and the terms "preferred numbers" and "series of preferred numbers" have very specific meanings in the international standards context. The terms are used in connection with a group of internationally agreed preferred number series, also referred to as Renard-series or R-series, which are series [or sequences] of numbers having a substantially constant ratio between successive terms. In addition, the series have a direct relationship to the decimal system of numbers, as their originating and terminating terms are powers of ten, such as 1, 10, 100, 1000, 10 000, etc. They can also consist of negative powers of ten--that is, values which represent decimal fractions.

This Section discusses and compares various concepts in series of numbers; but primarily focuses on the Renard-series of preferred numbers, which is of particular significance in the "free" approach to metrication.

2.5.2 Arithmetic Series

An arithmetic series is a progression of numbers in which each term is derived from the preceding one by the addition of a mathematically defined increment which can either be constant or variable.

Arithmetic series with constant increments are most common. They can begin with any number, A_1, and progress in <u>equal increments</u>, d. The n^{th} term in the series, A_n, where n is a whole number [or an integer], is given by: $\underline{A_n = A_1 + (n - 1)\,d}$.

Arithmetic series with a variable increment occur where term values are formed by the addition of preceding term values. The best known example is the Fibonacci series, in which each value represents the sum of the two preceding values: 0, 1, 1, 2, 3, 5, 8, 13, 21, 34, ...

Arithmetic series have traditionally been used in selection tables for design criteria, such as a range of design temperatures in increments of 5[°C] or 10[°C]:

0, 5, 10, 15, 20, 25, 30, 35, ... or 0, 10, 20, 30, 40, ...

Other examples are tabulations of preferred dimensions in a given range; for example, stair tread widths in increments of 10 [mm] starting from 240 [mm]; or values for preferred horizontal controlling dimensions in building in multiples of 600 [mm].

Traditionally, arithmetic series have also been used for concrete strengths, steel reinforcing bar diameters, sheet thicknesses, etc., although some adjustments to such series have taken place over time to eliminate unnecessary term values, or to modify them. In many instances where arithmetic series are used with customary ranges of products or requirements, it will be useful to determine whether a geometric or preferred number series can provide more appropriate steps [or intervals] and assist rationalization by a reduction in variety.

Arithmetic number series predominantly utilize integers [whole numbers] as term values, and, in general, the preferences shown in the schedule of convenient numbers provide appropriate term values in most applications.

2.5.3 Geometric Series

A geometric series is a progression of numbers, where each term is derived from the preceding term by the multiplication with a constant factor. This factor is also known as the ratio, r.

In a geometric series beginning with any number, A_1, the n^{th} term in the series, A_n, is given by: $A_n = A_1 \cdot r^{(n-1)}$.

The best known geometric series results from the progression of powers of 2, $y = 2^n$, where n is a whole number. This leads to the series: 1, 2, 4, 8, 16, 32, 64, 128,.... This series has been used in U.S. customary units for the designation of liquid volume containers. The values 1 to 16 are expressed as fluid ounces, 16 is given the special name "pint," 32 given the special name "quart," and 128 given the special name "gallon."

The ISO preferred number series [or Renard-series] are geometric series, where the theoretical values have been rounded to more convenient numbers. These series are discussed in detail in Section 2.5.5, and following Sections.

2.5.4 Special Purpose Series: The 1-2-5 Series

The 1-2-5 series is a special purpose series which covers the range 1 to 10--or any decimal multiple of it--in three unequal steps. The numbers in this series are ...1, 2, 5, 10, 20, 50, 100, 200, 500, ..., and they can be extended in either direction by multiplying by a power of ten. The series has the advantage that all its terms are related to powers of ten by the factor 2 [halving and doubling].

Because of this intimate relationship to the decimal system of numbers, there will be many additional applications of this series during conversion to the metric system. The series is already in common use in paper money in the United States, and in the coinage of many other countries.

International precedent indicates that this series is likely to be used for scale ratios and scale factors, such as on drawings and maps. Packaging quantities for metric mass [weight] and volume are bound to utilize the 1-2-5 series; especially, as the use of term values in this series makes calculations of "unit prices" simple and convenient. Typical packaging sizes for mass in grams would be 50, 100, 200, 500, and 1000 [or 1 kg]; and in kilograms 1, 2, 5, 10, 20, etc. Similarly, container sizes in milliliters would be 50, 100, 200, 500; and in liters 1, 2, 5, 10, etc. [The familiar 26-gallon household refuse container actually has a capacity of 100 liters, which would be part of the series.]

Doubling or halving of the 1-2-5 series retains two of the terms of the series, but introduces a new value every third term, caused by the irregular step in the series. This is illustrated in a comparison of the 1-2-5 series with doubling and halving:

Doubled 1-2-5 Series:	2, <u>4</u>, 10, 20, <u>40</u>, 100, 200, <u>400</u>, 1000, 2000,....
<u>Basic 1-2-5 Series</u>:	1, 2, 5, 10, 20, 50, 100, 200, 500, 1000, 2000,....
Halved 1-2-5 Series:	0.5, 1, <u>2.5</u>, 5, 10, <u>25</u>, 50, 100, <u>250</u>, 500, 1000, <u>2500</u>,

[Values outside the 1-2-5 series have been underlined]

The halved 1-2-5 series sometimes is substituted for the 1-2-5 series, because it has doubling steps ending in a power of ten, rather than starting from a power of ten. The disadvantage of this series occurs in term values such as 2.5, 0.25, 0.025, etc., which have an additional place of decimals compared with the basic 1-2-5 series. With the exception of the 2.5 term value, U.S. coinage uses a halved 1-2-5 series between 1 and 100.

2.5.5 The Renard Series of Preferred Numbers

The need for a systematic method to cover a range with the fewest terms first occurred to the French engineer Colonel Charles Renard (1849 - 1905), between 1877 and 1879, when he made a rational study of the elements necessary in the construction of captive balloons. He found that 425 different sizes of cable were used for mooring purposes and, in working on various systems for the reduction of this variety, he finally developed a sizing system based upon a geometric series of values for mass per unit length, which only required 17 cables to cover the total range.

The Renard sizing system was based on a series of numbers chosen in such a way that every fifth step of the series increased the size by a factor of ten, i.e.:

$\underline{a \times g^5 = 10\ a}$ or $\underline{g = \sqrt[5]{10}}$

thus arriving at the following series of terms:

$$a,\quad a\sqrt[5]{10},\quad a(\sqrt[5]{10})^2,\quad a(\sqrt[5]{10})^3,\quad a(\sqrt[5]{10})^4,\quad 10\,a.$$

the values of which, when expressed to five significant figures, are:

<u>a, 1.5849 a, 2.5119 a, 3.9811 a, 6.3096 a, 10 a.</u>

Renard substituted more rounded and more practical values for the calculated values, and then he adopted "a" as a power of 10. He thus obtained the following series for a = 10:

<u>10, 16, 25, 40, 63, 100</u> [which may be continued in both directions].

The approximate ratio between the rounded values in the series is 1.6; that means that each term value is approximately 60 percent larger than the preceding one. [The actual ratio for the calculated values is 1.5849, or 58.49 percent.]

Renard's principle was subsequently applied successfully in other fields and eventually was adopted in international standards. The above series is now known as the R5 basic series--the R commemorating Renard. This series has 5 intervals, <u>but</u> six term values [numbers].

2.5.6 The ISO Preferred Number Series

In addition to the basic R5 series, the basic series R10, R20, and R40 were developed to give geometrically intermediate terms where closer intervals are required. [The "R" denotes a Renard-series, and the number indicates the particular root of 10 on which the series is based as well as the number of intervals in the series.]

There are four basic series:

i. The R5 series, with 5 intervals and 6 term values, approximately 60% apart, has a maximum rounding of theoretical values of +0.95%.

ii. The R10 series, with 10 intervals and 11 term values, approximately 25% apart, has a maximum rounding of theoretical values of +0.95% and includes all values in the R5 series as alternate steps.

iii. The R20 series, with 20 intervals and 21 term values, approximately 12% apart, has a maximum rounding of theoretical values of +1.22% and includes all values of the R10 series as alternate steps.

iv. The R40 series, with 40 intervals and 41 term values, approximately 6% apart, has a maximum rounding of theoretical values of +1.22% and includes all values of the R20 series as alternate steps.

The adoption of the basic number series was recommended by the International Organization for Standardization [ISO] Technical Committee [TC] 19, Preferred Numbers, in 1949. An additional series, the exceptional R80 series with 80 intervals and 81 term values, was added in ISO Recommendation R 3 in 1953. Further material dealing with guidance as to the use of preferred numbers was prepared and included in ISO Recommendation R 17, in 1955. In that document, a brief reference to more rounded values of preferred numbers was also included. In 1966, ISO Recommendation R 497 "Guide to the Choice of Preferred Numbers and of Series Containing More Rounded Values of Preferred Numbers," was published and thus enlarged the international system of preferred numbers by recognizing a need to round some values in the series to whole numbers [integers] or to more convenient numbers. In 1973, the three Recommendations became full international standards: ISO 3; ISO 17; and, ISO 497. They are used widely in the drafting of other international standards because they provide better opportunities for securing international harmonization and variety reduction through standardization.

The more rounded series are designated with a single prime for the first rounding [such as R'10, R'20, and R'40], and with a double prime for the second rounding [such as R"5, R"10, and R"20].

The basic series of preferred numbers R5, R10, R20, and R40, and the more rounded series R"5, R'10, R"10, R'20, R"20, and R'40 are listed in Table 7, on page 31. The calculated values have been included for reference. The table contains preferred values in the Range 10 to 100, rather than 1 to 10, in recognition of the fact that this will show more whole numbers.

Each series may be continued in both directions by choosing a larger or smaller power of ten as multiplier, and this "expansion" is illustrated for the R5 series in Table 8, on page 31.

Table 7

SERIES OF PREFERRED NUMBERS

Basic Series: R5, R10, R20, R40

Rounded Series: R'10, R'20, R'40 [First Rounding]

R"5, R"10, R"20 [Second Rounding]

R5	R"5	R10	R'10	R"10	R20	R'20	R"20	R40	R'40	Calculated values
10	10	10	10	10	10	10	10	10	10	10.000
								10.6	10.5	10.593
					11.2	11	11	11.2	11	11.220
								11.8	12	11.885
		12.5	12.5	12	12.5	12.5	12	12.5	12.5	12.589
								13.2	13	13.335
					14	14	14	14	14	14.125
								15	15	14.962
16	15	16	16	15	16	16	16	16	16	15.849
								17	17	16.788
					18	18	18	18	18	17.783
								19	19	18.836
		20	20	20	20	20	20	20	20	19.953
								21.2	21	21.135
					22.4	22	22	22.4	22	22.387
								23.6	24	23.714
25	25	25	25	25	25	25	25	25	25	25.119
								26.5	26	26.607
					28	28	28	28	28	28.184
								30	30	29.854
		31.5	32	30	31.5	32	30	31.5	32	31.623
								33.5	34	33.497
					35.5	36	35	35.5	36	35.481
								37.5	38	37.584
40	40	40	40	40	40	40	40	40	40	39.811
								42.5	42	42.170
					45	45	45	45	45	44.688
								47.5	48	47.315
		50	50	50	50	50	50	50	50	50.119
								53	53	53.088
					56	56	55	56	56	56.234
								60	60	59.566
63	60	63	63	60	63	63	60	63	63	63.096
								67	67	66.834
					71	71	70	71	71	70.795
								75	75	74.989
		80	80	80	80	80	80	80	80	79.433
								85	85	84.140
					90	90	90	90	90	89.125
								95	95	94.405
100	100	100	100	100	100	100	100	100	100	100.000

Table 8

EXPANSION OF THE R5 SERIES

Basic Series	1	1.6	2.5	4	6.3	10
Divided by 10	0.10	0.16	0.25	0.40	0.63	1.00
Multiplied by 10	10	16	25	40	63	100
Multiplied by 100	100	160	250	400	630	1000
Multiplied by 1000	1000	1600	2500	4000	6300	10 000

2.5.7 Limited Series

Many standardization situations arise where it is desirable to limit a series of numbers at the lower end, upper end, or between limiting values. Any of the R-series may be limited by the following methods to indicate the limit(s):

- R10 (16......) indicating an R10 series with the term value 16 as the low limit;
- R"5 (......60) indicating an R"5 series with the term value 60 as the high limit;
- R'20 (16.....80) indicating an R'20 series limited to all values between the term values 16 and 80 inclusive.

2.5.8 Derived Series

Derived series are series of preferred numbers in which every second, third, fourth, or p^{th} term of one of the basic series is used. Derived series are distinguished by the symbol of the corresponding basic series followed by the solidus sign and the appropriate number (2, 3, 4, ...p). If the series is limited, the limiting value(s) must be shown; if it is not, at least one term value must be mentioned to avoid ambiguity, as indicated by the following examples:

- R5/2 (1.....1 000 000) indicating a series derived by taking every second term of the R5 series, starting with 1 and terminating with 1 000 000;
- R10/3 (....80....) indicating a series derived by taking every third term of the R10 series, unlimited in both directions, but including the term value 80;
- R20/4 (112.....) indicating a series derived by taking every fourth term of the R20 series, with the term value 112 as the low limit;
- R40/5 (......60) indicating a series derived by taking every fifth term of the R40 series, with the term value 60 as the high limit.

Note: The derived series R10/3 (1.....), which takes every third term in the basic R10 series starting with the term value 1, comprises the following terms: 1, 2, 4, 8, 16, 31.5, 63, 125, 250, 500, 1000, 2000, ...; it has a ratio of approximately 2, and repeats itself for all multiples of 1000. The R10/3 (1.....) derived series has 10 intervals and 11 term values within each range of 1000. The series represents a reconciliation between a doubling series starting from 1 [1, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024] using the first five term values of that series, and a halving series starting from 1000 [1000, 500, 250, 125, 62.5, 31.25, ...], using the term values 125....1000 of that series. A reconciliation and transfer of term values is effected in the preferred numbers 31.5 [32--31.5--31.25] and 63 [64--63--62.5].
This series has been used widely in international standards.

2.5.9 Characteristics of ISO Preferred Number Series

The most significant characteristics of the ISO [Renard] preferred number series include:

- each basic series can be extended to any positive or negative power of ten;
- each term in a series differs from the preceding one by an (approximately) constant factor to provide the best geometric progression from the point of view of regularity;

- the logarithms of the terms in the series form an arithmetic series--that is, their values differ by a constant increment. The mantissae of the theoretical values in the R5 series differ by 2000, in the R10 series by 1000, in the R20 series by 0500, in the R40 series by 0250, and in the exceptional R80 series by 0125.
  Where new requirements demand the creation of a closer series of values, this provides the opportunity to insert intermediate values from the next series without departing from preferred numbers;

- for calculations involving preferred numbers it is advisable to use the theoretical values or logarithms to avoid any build-up of error caused by the use of rounded values. The use of logarithms (to base 10) facilitates calculations involving multiplication, division, or exponentiation. The sum or difference of preferred numbers normally will not be a preferred number; however, the product, quotient, or any integral positive or negative power of preferred numbers will be a preferred number. Squaring the terms of the R10 series produces an R5 series [approximately; and exactly, where theoretical values are used], and this relationship also holds for R20 to R10, R40 to R20, etc.;

- the more rounded series provide more sensible and practical values where whole numbers [integers] are required--for example, the number of teeth on a gear wheel must be a whole number;

- the term 3.15, which is a close approximation to π [3.1416] and $\sqrt{10}$ [3.1623], occurs in the R10, R20, and R40 series. It follows that where a circle's diameter is a preferred number, its circumference and area may also be expressed with good accuracy by preferred numbers; and this relationship also extends to peripheral speeds, cutting speeds, cylindrical areas and volumes, and spherical areas and volumes.

Preferred numbers are useful in standardization, rationalization, and size selection and should be considered in new product development as well as metrication situations. Apart from ensuring a regular progression in covering requirements in a given field, the use of preferred numbers improves the likelihood that sizes and ranges of sizes will be left unchanged by future standardization work, whether on a corporate, national, or international basis. The application of preferred numbers to those product properties which form the basis for product selection will limit unnecessary variety, reduce inventories and increase production runs. Preferred numbers can be applied to primary functional characteristics of a product, such as its strength grade or other mechanical properties, without unduly restricting the product's detailed design or manufacture.

Typical characteristics that may be expressed by a series of preferred numbers include:

lengths (including diameters, circumferences, line thicknesses, etc.)
areas
volumes, volume flow rates
masses, mass per unit area
forces
pressures/stresses
powers, power ratings
time intervals
speeds [linear, rotational]
concentrations
voltages, currents
proportions, ratios

2.5.10 Covering a Range with Preferred Numbers

The versatility of the ISO preferred number series can be appreciated better by means of an example which shows the variety of alternative sets of preferred numbers that may be used to cover a specific functional range. In addition to the R5, R10, R20, and R40 series, the derived R20/5 (1......) series in fact becomes an R4 series with 4 steps [5 numbers] and a substantially constant factor between successive term values [1.0, 1.8, 3.15, 5.6, 10.0]; and the derived R40/5 (1......) series becomes an R8 series with 8 steps [9 numbers] and a substantially constant factor between successive term values [1.0, 1.32, 1.8, 2.36, 3.15, 4.25, 5.6, 7.5, 10.0].

This makes it possible to choose preferred numbers within a given range which subsequently may be expanded by additional values without giving up the concept of preferences.

For example, if a working range between 100 and 400 is to be covered by a set of related preferred values, this can be done with a variety of steps, all of which can be found in the basic preferred number series, as shown below:

2 Steps 3 Numbers [R10/3]	3 Steps 4 Numbers [R5]	4 Steps 5 Numbers [R20/3]	6 Steps 7 Numbers [R10]	8 Steps 9 Numbers [R40/3]	12 Steps 13 Numbers [R20]
100	100	100	100	100	100
					112
				118	
			125		125
		140		140	140
	160		160		160
				170	
					180
200		200	200	200	200
					224
				236	
	250		250		250
		280		280	280
			315		315
				335	
					355
400	400	400	400	400	400
Ratio: 1:2	Approximate Ratio: 1: 1.6	Approximate Ratio: 1: 1.4	Approximate Ratio: 1: 1.25	Approximate Ratio: 1: 1.18	Approximate Ratio: 1: 1.12

The application of preferred numbers for functional characteristics has the advantage that a numerical range can be modified in the following manner:

- addition to the range; for example, going from 5 values [R20/3] to 9 values [R40/3]
- deletion from the range; for example, going from 13 values [R20] to 7 values [R10]
- substitution within the range; for example, going from 13 values [R20] to 9 values [R40/3] by retaining every fourth term value and substituting every second value in the R40/3 series for two values in the R20 series
- supplementing the range with specific values to satisfy specific demand; for example, by using the term values of the R10 series [7 values] and adding the term values 180 and 224 from the R20 series to meet a peak demand (assumed) in the range 160 to 250.

2.5.11 The Combination of Preference Systems for Sizing (Linear Dimensions) in Engineering

Section 2.5.10 indicates how a range can be covered with a variety of steps by selecting numbers from various Renard series. However, the preferred number series suffer from two disadvantages where linear measurement in engineering design is concerned: first, the gaps between the term values become very large at the top end of the scale; and, second, the preferred number series contain values that are awkward and difficult to use in many design and production situations. This is relieved somewhat by the more rounded Renard series.

During the change to SI units, standardization committees in Britain, Australia, and Canada recognized the need to develop a special set of preferences for sizes [linear dimensions] in engineering design which would provide convenient whole numbers and fill in the gaps between larger sizes in the Renard series, while still reducing the variety of alternatives.

Australian Standard AS 1122 - 1973 "Recommended Metric Sizes for Engineering," addresses three ranges of linear dimensions between 1 mm and 1000 mm, and identifies an increasing number of graduated choices (first, second, third) for each range, thus providing a system of preferences within recommended preferred sizes. The number of preferences are:

	Range of Application	First Choices	Second Choices	Third Choices
Range 1	Numbers from 1 - 10	11	11	18
Range 2	Numbers from 10 - 100	18	17	22
Range 3	Numbers from 100 - 1000	28	27	44

The first choices include the following term values:

Range 1: 1, 1.2, 1.6, 2, 2.5, 3, 4, 5, 6, 8, 10

Range 2: 10, 12, 16, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 90, 100

Range 3: 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 220, 240, 260, 280, 300 350, 400, 450, 500, 550, 600, 650, 700, 750, 800, 900, 1000

The choices show an affinity to rounded Renard series R"10 for Range 1 (identical except the term value 1.6 has been used in lieu of 1.5), rounded Renard series R"20 for Range 2 (the term values 11, 14, 18, 22, and 28 have been relegated to second choice, while the term values 65 and 75 have been added), and rounded Renard series R'40 for Range 3 (25 of the 28 first choices are found in R'40). However, to prevent a widening of gaps between term values in the higher range, arithmetic increments have been introduced into Range 3, with arithmetic steps of 10 between 100 and 200, arithmetic steps of 20 between 200 and 300, and arithmetic steps of 50 between 300 and 800.

British proposals are outlined in the British Standards Institution document PD 6481 : 1977, "Recommendations for the Use of Preferred Numbers and Preferred Sizes," which superseded two earlier documents, BS 4318 and DD 29. They are identical to Australian proposals up to 300 mm but differ thereafter by continuing arithmetic increments in first, second and third choices, thus introducing a much larger selection of values than the Australian standard. Appendix C, page 72, is reproduced from PD 6481 : 1977, and illustrates graphically the comparison of preferred numbers from the R5, R10, R20, and R40 series, with preferred sizes in the range 1 mm to 400 mm.

2.5.12 Comparison of Arithmetic and Geometric Number Series

In the selection of number series for use in technical information, such as specifications, standards, codes, and other technical data, it is necessary to clearly establish the purpose of the number selection and the dominant functional criteria.

Arithmetic series are most useful where it is desirable to base selections on an addition or subtraction of a constant value to or from a base value to yield regular increments within a specific design or operating range. Arithmetic series are more suitable where calculations or measurements involve sums or differences. In general, the terms in an arithmetic series should be integers.

Geometric series are most useful where the selection criteria or the reference quantities involve a geometric factor or progression. Such situations are best served by a sequence of numbers with a substantially constant ratio [or factor] between successive terms. Geometric series are more suitable where calculations or measurements involve products, quotients, or exponentials, such as in areas, volumes, forces, pressures/stresses, powers, concentrations, flow rates, etc.

In customary measurement, the numerical values in a series were generally selected from an arithmetic or a geometric numerical sequence. A typical example of an arithmetic series is compressive strength of concrete at 28 days [psi]: 2000, 2500, 3000, 3500, 4000, 4500, 5000, with steps of 1000 psi thereafter. A typical example of a geometric series can be found in container sizes [in fluid ounces], with each container size representing a factor of two--or doubling--of the preceding size: 1, 2, 4, 8, 16 (1 U.S. pint), 32 (1 U.S. quart), 64, 128 (1 U.S. gallon), etc.; however, over time additional sizes outside this series have been added.

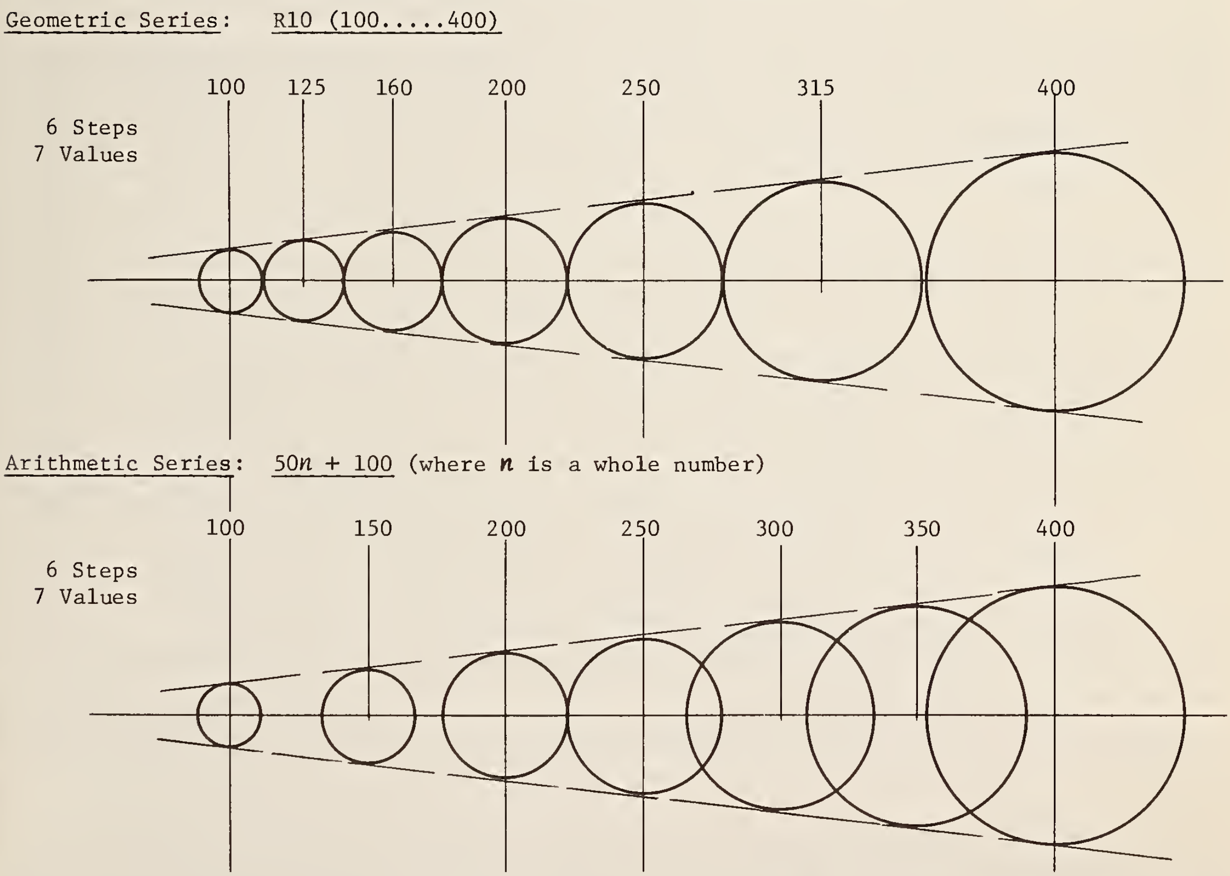
If an arithmetic series is used where the principal demand criterion has a geometric progression, this will introduce inadequate coverage at the lower end of a series because the interval is too large, and "bunching" at the upper end of the series due to overlap. One example of the use of a "nominal" arithmetic series where a geometric series might provide a better coverage can be found in the range of customary mild steel reinforcing bars [rebars] for concrete, which features arithmetic increments between #3 [3/8" ϕ] and #8 [1" ϕ], near arithmetic increments between #8 and #11 [1.41" ϕ] bars, and out of step jumps to #14 [1.693" ϕ] and #18 [2.257" ϕ] bars. In a comparison of percentage increases in bar areas, the "gaps" at the lower end and the "bunching" at the middle of the range can be discerned clearly:

Bar Designation	Diameter [in]	Area [in^2]	Area [mm^2]	Percentage Increase in Area
#3	0.375	0.11	71	---
#4	0.500	0.20	129	81.7
#5	0.625	0.31	200	55.0
#6	0.750	0.44	284	42.0
#7	0.875	0.60	387	36.3
#8	1.000	0.79	510	31.8
#9	1.128	1.00	645	26.5
#10	1.270	1.27	819	27.0
#11	1.410	1.56	1006	22.8
#14	1.693	2.25	1452	44.3
#18	2.257	4.00	2581	77.8

In a geometric series, the ratio between terms--the percentage increase--would be constant, so that such a series provides an optimum coverage of a range from the point of view of progression. For example, in the R10 series of preferred numbers [1.0, 1.25, 1.6, 2.0, 2.5, 3.15, 4.0, 5.0, 6.3, 8.0, 10.0], the ratio between successive terms is approximately 1.25 [a percentage increase of approximately 25 percent]. If such a sequence were to be utilized in the sizing of products within a geometric range there would be no gaps or overlaps.

Figure 3 provides a graphical comparison of a geometric series with 6 steps [7 term values] and an arithmetic series with 6 steps [7 term values]. The representation of circles based on the geometric preferred number series R10 (100.....400) shows a constant ratio with no gaps or overlaps. The representation of circles based on the arithmetic series $50n + 100$ (100......400), where n is a whole number, shows considerable gaps at the lower end, and some degree of overlap at the upper end. Yet the two series have 4 term values in common--100, 200, 250, and 400.

Figure 3 GRAPHICAL COMPARISON OF A GEOMETRIC SERIES AND AN ARITHMETIC SERIES WITH THE SAME NUMBER OF STEPS AND TERMS BETWEEN 100 AND 400.



During the change to SI, various number series or sequences can be utilized to provide the best functional progression of values. Where the requirements within a set reflect geometric properties or an exponential factor, a geometric progression is generally more appropriate to cover a range than an arithmetic one. This means, that even though an arithmetic progression may have been associated with a property or characteristic in customary units, a geometric series may be far more suitable from the point of view of an optimum [product] range; thus it is desirable to assess whether metrication can be utilized as the opportunity to make such a transfer in tandem with the change to new numerical values.

Various precedents have been established in other countries that have changed to SI and in international standards. These precedents show that preferred numbers series (geometric progressions) can provide optimum technical as well as economic solutions by reducing the number of [product] alternatives and unnecessary variety. It is appropriate to examine international precedent in each product area before a final selection of metric requirements is made. The traditional or most obvious approach to a range of requirements is not in all cases the most appropriate when functional and economic factors are taken into account, and the metric chance to review and rationalize traditional approaches will only come once.

Table 9 shows the variety of alternative number progressions that can be used to cover a range from 100 to 400 with number series containing 3, 4, 5, or 6 steps [4, 5, 6, or 7 terms].

Table 9 MATRIX OF ALTERNATIVE NUMBER SERIES IN THE RANGE 100 TO 400

Number of Terms	Type of Series	Interval	Formula	Values (including 100 and 400)
4	arithmetic	regular	$100 + 100n$	100 200 300 400
4	arithmetic	irregular	$100 + \Sigma 50n$	100 150 250 400
4	geometric [R5]	irregular	$100(\sqrt[5]{10})^n$	100 160 250 400
4	geometric [R"5]	irregular	$100(\sqrt[5]{10})^n$	100 150 250 400
5	arithmetic	regular	$100 + 75n$	100 175 250 325 400
5	geometric [R20/3]	irregular	$100(\sqrt[20]{10})^n$	100 140 200 280 400
6	arithmetic	regular	$100 + 60n$	100 160 220 280 340 400
6	arithmetic	irregular	$100 + \Sigma 20n$	100 120 160 220 300 400
7	arithmetic	regular	$100 + 50n$	100 150 200 250 300 350 400
7	geometric [R10]	irregular	$100(\sqrt[10]{10})^n$	100 125 160 200 250 315 400
7	geometric [R'10]	irregular	$100(\sqrt[10]{10})^n$	100 125 160 200 250 320 400
7	geometric [R"10]	irregular	$100(\sqrt[10]{10})^n$	100 120 150 200 250 300 400

The table confirms that a variety of solutions exists for any number of terms within a specified range of values, and that the most obvious solution may, at times, not be the most appropriate solution.

For linear measurement in buildings, preferred dimensions form a special selection of values from arithmetic series derived from multiples or submultiples of 100 mm, and, therefore, have been discussed as a separate set of preferred values in Section 2.4.

PART 3: A METHODOLOGY FOR THE SELECTION OF PREFERRED METRIC VALUES IN A MANUAL OR AN AUTOMATED APPROACH.

3.1 General

The change to metric [SI] units in building design, production, and construction requires the replacement of existing quantitative data with converted and/or revised information. This activity must be substantially completed before it is possible to undertake the actual change to true metric operations with fully metric design, specification, estimating, and construction. Therefore, the timely preparation of metric technical information is a key activity in the metric conversion program for the U.S. construction community.

The tasks associated with the conversion and rationalization of all technical documents will be time consuming because, in addition to the mathematical processes of direct conversion and rounding, it will be necessary to review data before and after conversion and to obtain consensus on the metric technical information. To minimize this time requirement, and yet ensure that "preferred metric values" are chosen if at all practicable, it is desirable to have an agreed methodology for the conversion of technical data which can be applied by all segments of the industry and its related sectors.

Basically, the conversion to metric units of specifications, standards, codes, and other technical information involves the following processes:

[a] the identification and listing of all numerical values and measurement statements;

[b] the analysis of the nature of each value and assessment of any dependencies;

[c] the conversion of existing values to SI units, and the rounding of such values;

[d] the review and rationalization of values, including the substitution of new sets or series of metric values where appropriate; and,

[e] the selection, from all alternatives, of the most suitable metric values.

Processes [a], [b], and [e] require the technical judgment of an individual or a committee and manual processing--they cannot be automated. However, processes [c] and [d] may be simplified and speeded up, as well as standardized, through the use of automated techniques, such as the use of electronic data processing.

It is suggested that conversion of existing technical information proceed initially on the premise that existing numerical values are close approximations to desirable criteria and not just random choices. Although customary values have been evolved and tested over a lengthy period of time, they should not be regarded as sacrosanct and immune to changes or review. The metric opportunity to reexamine and improve the technical data base will only come once and should not be missed.

A well planned, systematic approach is desirable to ensure the most meaningful selection of metric values, to avoid conflict by preserving both internal and external consistency of technical values used in a variety of technical documents, and to obtain the greatest simplicity in the use and application of metric values. Wherever possible, preferred metric values should be identified and considered as the foremost alternative, particularly where their magnitude differs only by a small percentage from the magnitude of customary values.

In a few instances, it will be desirable--if not essential--to consider whether a particular value or measurement statement should be included in the metric version at all.

Thus, conversion is not simply a matter of slavish mathematical routine, but an issue of value analysis applied to technical data used by the construction and engineering industries. The outcome of such value analysis may well be the rationalization of values, either by setting new limits which reflect the current state of technology, or by selecting an optimum range of alternatives.

3.2 Identification and Listing of All Measurement Related Statements

The first task in metrication of technical information--one which can be started immediately--is the identification and sequential listing of all measurement related statements in customary units which will need to be changed to SI units.

The task of investigation requires considerable familiarity with the technical details, objectives, and intricacies of each document to be converted. In some cases, measurement values or relationships are not indicated by numbers but may be written out in full or implied in some other way.

A suitable means of identification is the marking or highlighting [in color] of all relevant statements. Further, it is recommended that all values thus identified be given a chronological number, so that subsequent cross-referencing is simplified.

This task of identification and listing is best undertaken by someone with the technical responsibility for the existing document or, in the event of a committee responsibility, the committee secretary or one of the members by delegation.

The identified measurement statements should be listed in the first three columns of a "conversion schedule," setting out the following information:

- [a] the chronological number of the measurement statement [for identification purposes];
- [b] the page number and/or clause number in the document [for cross-referencing]; and,
- [c] the existing (customary) value, with the number <u>always</u> shown first, followed by the unit of measurement.

3.3 Analysis of the Nature and Dependency of Each Value

Before any conversion is attempted, it is desirable to assess the nature and/or dependency of each measurement sensitive statement because both of these factors will have a bearing on the degree of freedom in the conversion process.

Columns should be reserved in the conversion schedule for the identification and referencing of the following information:

[a] the type of value [to provide some measure of the exactitude required in conversion];

[b] limits or limitations [to give an indication of freedom in conversion, the direction of such freedom, and/or the range within which rounding will be permissible]; and,

[c] dependencies [to indicate the effect of conversion on other values, and/or the effect of other values on conversion, both within the document to be converted and within other related documents].

To conserve space in the conversion schedule, symbols or abbreviations may be used to represent information dealing with the nature and dependency of values. In some cases, conversion introduces many dependencies, so that a column may just indicate whether or not any dependencies exist, with a separate schedule listing any such dependencies.

3.3.1 Types of Numerical Value

Before attempting the conversion or specification of metric values in technical information, it is essential to distinguish between different types of value, so that an appropriate degree of precision can be applied in the selection of a "new" metric value. For example, where a value appears to have been or has been chosen initially for reasons of numerical convenience, it is hardly appropriate to effect an exact conversion, since rounding by up to 5%, or even 10%, may be quite acceptable in many instances and, therefore, permit the selection and substitution of a preferred metric value.

While various connotations can be attached to a numerical value, such as: exact, absolute, standardized, specified, approximate, nominal, or actual [measured], the suggested approach distinguishes between three types:

i. PV - Precise Value

A precise value signifies an exact numerical value established under strictly specified conditions and decided and agreed internationally, or a recognized standard value which has been assigned to a physical or mechanical property or condition, determined as a result of accurate measurement or computation.

A precise value has an accuracy which is established independently of the measurement system, but is frequently rounded [or, in the case of variable conditions, standardized] to a workable and meaningful number. Many precise values initially have been established in metric units and then rounded to customary values. In general, where precise values are converted, the SI value should have the same level of precision as the customary value.

Some precise values are "defined," such as absolute (zero) temperature [-273.15°C = 0 K], or the internationally standardized value for acceleration due to gravity (g) which has been standardized at 9.806 65 m/s^2. Other values, such as melting points of materials, or design factors, in most cases are rounded to the nearest whole number in customary measurement, and it is preferable to go back to precise values before metric conversion is attempted; for example, in the case of moduli of elasticity.

The number of precise values likely to occur in construction and engineering specifications, standards, codes, and other technical data is very small.

It is suggested that the abbreviation "PV" be used in the conversion schedule to denote a value which is a precise or accurate value.

ii. GV - General Value

A general value, as used in this publication, signifies a "convenient reference value," normally stated as a simple numerical expression to facilitate description, reference, or calculations. General values frequently indicate an "acceptance level," such as an upper limit, a lower limit, or a mean value with explicit or implicit tolerances. General values used in dimensional coordination may also include joint allowances. To facilitate the choice of a convenient metric replacement value, it is desirable to indicate acceptable tolerances and/or limits, where such exist.

Some typical examples of "general values" in customary standards include: a minimum dimension for a habitable space of 7 feet; a maximum floor area of 15,000 square feet; and, a yield strength of 50,000 psi. To achieve equivalent simplicity in the metric replacement values, conversion and minor rounding might lead to the following values: 2100 mm [-1.6%]; 1400 m^2 [+0.5%]; and, 350 MPa [+1.5%].

General values form the backbone of the standardization process, and the percentage of such values in specifications, standards, codes, and other technical data is large. It is suggested that the abbreviation "GV" be used in the conversion schedule to denote any value which may be classified as a "general value," except designated values.

iii. DV - Designated Value

A designated value, as used in this publication, constitutes a [nominal] value assigned for the purpose of a simplified description or designation only, thus existing in name only. Designated values occur mainly in the products sector, such as, where historical descriptions have been retained despite changes in manufacturing sizes [building lumber], or where a group of shapes carries a common designation [structural steel shapes].

Where a conversion of designated values is required, such values should always be reverted to the accompanying permissible or specified values before converting. For example, if a designated lumber size of 2" x 4" [51 mm x 102 mm]--which represents a minimum permissible size of 1 $^1/_2$" x 3 $^1/_2$"--must be converted, the conversion should be based on the minimum size [38 mm x 89 mm, or 40 mm x 90 mm] rather than the designated size [51 mm x 102 mm, or 50 mm x 100 mm].

It is preferable to avoid the introduction of designated [nominal] values in the metric measurement environment.

Two additional types of value will be encountered in practice and need to be understood:

iv. Approximate Values

An approximate value is an imprecise value or factor used for quick checking or for the purpose of approximations; for example: 10 m/s^2 approximates acceleration due to gravity; 350 m/s approximates the speed of sound in air; and, 100 kPa approximates standard atmospheric pressure. Approximations are frequently used to facilitate the recognition of metric units in terms of customary values or customary units in terms of metric values; for example: 100 mm is approximately 4 inches, 1 horsepower is approximately 750 W.

Approximate values should never be used in specifications, standards, codes, or other technical documents, unless it is made quite clear that approximations have been included for recognition or quick checking purposes only, and are identified unequivocally as "inexact" values.

v. Actual [Measured] Values

An actual value is one which has been established by an actual physical measurement. While actual values should match or be very close to specified values, deviations from requirements set out in specifications, standards, or codes occur in practice, depending upon inaccuracies or errors introduced during manufacturing and/or assembly operations. The principal purpose of technical information for building or engineering applications is to ensure that the "actual values" fall within the permissible limits of size, amount, or position--that is, within the permitted tolerances.

Actual values should be expressed to the degree of precision required by the tolerances, rather than the reference value. For example where a value of 6 meters is specified, with an acceptable tolerance of ±0.25%, the actual value must be found between 5.985 m [5985 mm] and 6.015 m [6015 mm] for purposes of compliance. Another form of expression would be 6000 mm (± 15 mm).

Actual values are of considerable significance in renovation, retrofit, or repair work, in which correct fit or replacements are determined by the "actual" measurement of existing dimensions, sizes, or other physical quantities. Because most actual values will differ slightly from the specified values due to deviations in production, it is strongly recommended that the use of values stated in drawings or specifications be avoided to prevent mismatch or misfit. To avoid the introduction of a conversion error, actual values for use in a metric measurement environment should always be measured in SI units, and not in customary units with a subsequent conversion.

3.3.2 Limits

Most requirements in construction or engineering specifications, standards, or codes are set down as upper or lower limits, stated in terms such as "not more than," "shall not exceed," "maximum," or, "not less than," "at least," and "minimum." These limitations become highly significant in the metrication context, because the direct conversion of existing values may preclude the use of preferred metric values. Similarly, the selection of preferred metric values without consideration of their equivalent in customary units may preclude the use of preferred customary values during the early part of the transitional period. Ideally, new metric values should be chosen in such a way that the metric equivalent of customary maxima or minima will still be acceptable during the transitional period.

A good example of the considerations that are relevant in relation to limits is found in the conversion of a minimum dimension of 8 feet. The soft conversion, rounded to the nearest millimeter, yields a metric equivalent of 2438 mm. If, during conversion, this minimum is rounded to 2440 mm, or a more rounded value of 2450 mm, this would not only preclude the use of the exact equivalent of 8 feet, but also a "preferred" metric dimension of 2400 mm [a 1.6% reduction of the previous limit]. Technically, therefore, a metric value of 2440 mm or 2450 mm would become severely restrictive. However, the choice of the less restrictive value of 2400 mm (7'-10 $^1/_2$") will allow the use of all alternatives--the preferred metric dimension, 2400 mm, the direct conversion of 2438 mm, the soft conversion of 2440 mm, and a more rounded value of 2450 mm or 2500 mm.

Therefore, before attempting a conversion it is desirable to establish an indication of the degree of freedom in metric conversion situations involving technical information. Requirements should only be made more stringent where a strong technical or economic reason exists to do so.

The conversion schedule might include an index of the type of limitation associated with each numerical value, indicated by an abbreviation. Three broad types of limitation can be distinguished:

i. UL - Upper Limit

An upper limit represents a maximum value for design, production, or construction which is generally expressed as a convenient or preferred numerical value. Typical examples include: maximum floor areas in buildings, maximum distances from an exitway, maximum height of a riser in a stairway, maximum operating temperature, extreme fiber stress, etc.

ii. LL - Lower Limit

A lower limit represents a minimum value for design, production, or construction which is generally expressed as a convenient or preferred numerical value. Typical examples include: minimum ceiling height, minimum room width, minimum building set-back, minimum level of illumination, minimum compressive strength, minimum yield strength, etc.

iii. MV - Mean Value

A mean value represents a requirement or recommendation which is expressed as a "mean" or "average" value, generally for the purpose of providing a convenient or preferred reference value. To give such a value meaning, it is necessary to ascertain the range which is covered by the mean, and/or the test or verification methods that are used. Typical examples are: average illumination levels, mean design speed, average compressive strength of test specimens, etc.

3.3.3 Dependencies

In many instances, numerical values stated in specifications, standards, codes, and other technical data are related to and/or dependent upon associated values which may be shown elsewhere in the same document or in other documents. In some cases, a dependency may be introduced by a formula or equation with separate components requiring conversion.

Any such dependencies must be taken into consideration in the selection of metric values, as a unilateral conversion without cross-referencing can easily introduce inconsistencies by altering the relationships in dependent statements. The change to a preferred value in one component of a dependency is almost certain to require a compensating change in the other to maintain an intended relationship or ratio. For example, in the expression of a desired illumination level at a given work plane height, a decision will need to be made whether the existing requirement of 3 footcandles [32.3 lx] at a work plane level of 30 inches [762 mm] can be changed to convenient or even preferred numbers unilaterally or in tandem. Alternative work plane heights, in millimeters, would be 700 mm, 750 mm, or 800 mm. It is known that the illumination level decreases with distance from the light source; thus, if the objective in conversion is to preserve equivalence in a measurement statement with two components, the following alternatives offer themselves in the conversion process:

Exact Conversion:	32.3 lx @ 762 mm
Lower Work Plane Level:	30 lx @ 700 mm
Similar Work Plane Level:	32 lx @ 750 mm
Higher Work Plane Level:	35 lx @ 800 mm

[This example has been included for illustrative purposes only.]

More significant and complex dependencies occur in relation to the specification of structural properties; for example, in tables showing maximum spans for floor joists under different conditions of loading. The change to preferred metric values for design floor loads will affect the permissible span and/or spacing of floor joists; the change to new span lengths or spacings will alter the load carrying capacity or required size of section; the change to new cross-sectional sizes of joists will affect permissible spans, spacings, shear strength, and other properties; and a change to new strength properties for the joist material would introduce another modifying factor. This example indicates a significant need for "decision analysis of interdependent functional relationships" and the usefulness of an information network which ensures cross-correlation of dependent variables during the metrication process. The field of multiple dependencies in technical information is an area for detailed analysis and research to ensure functionally acceptable relationships in a metric environment.

Where one or more dependencies arise out of a mathematical equation or formula, careful checking is needed to ensure that any measurement sensitive parts are suitably converted, and that any ratios between customary units are identified, isolated, and not transferred into the metric equation or formula.

3.4 Conversion and Rounding of Numerical Values in Technical Information

3.4.1 Overview

Section 1.8 deals with approaches to conversion of numerical values, and defines exact conversion, soft conversion, hard conversion, and rationalization.

The "conversion" and "rounding" of data to numerical values suitable for use with SI units is an activity which can be undertaken as soon as all measurement sensitive statements have been identified, listed, and analyzed as to their nature and dependency. Much has been written about the processes of conversion and rounding, and various techniques or approaches have been recommeded. Almost invariably, a direct conversion of existing values will lead to more complex numerical values in SI expressions. Therefore, direct conversion is merely a transitional device to permit the change from one measurement system to another, but it is no substitute for basic "rationalization" of values or intendependencies of values.

3.4.2 Use of Conversion Factors

The general precision of specifications, standards, codes, and associated technical data for use in construction and related engineering is such that conversion factors shown to four significant figures will normally provide adequate "correspondence" of metric equivalents. Therefore, unless great precision is required, an "exact conversion" using conversion factors with four significant figures will provide an adequate basis for subsequent rounding. It is important, however, to make sure that "authoritative" conversion factors are used, as well as recommended SI working units.

Special care needs to be exercised with foreign data or documents, since quite a few U.S. customary units have identical unit names to Imperial [or U.K.] units, but differ in magnitude. Typical examples are: ton, ton-force, gallon, quart, pint, and fluid ounce; as well as compound units, such as pound per gallon, mile per gallon, gallon per minute, etc. For consistency, it is suggested that conversion factors shown in ASTM E380-76 (revised), also issued as ANSI Z210.1 and IEEE Std. 268, and/or ANSI/ASTM E 621-78 be used. [See Appendix D.]

Conversion factors should <u>not</u> be rounded prior to a multiplication or a division--only the resultant value should be rounded.

3.4.3 Conversion Aids

In addition to conversion factors, conversion tables or graphical conversion aids may also be used, but it should be understood that such aids will generally be less accurate.

Conversion tables are generally constructed to show conversions for selected customary values to three, four, or five significant digits in matrix form. Such tables will be most useful in conversion situations involving integers [whole numbers], when a programmable calculator or authoritative conversion factors are not available.

Graphical aids, such as straight line charts [nomographs], or coordinate charts [showing multiple relationships], provide useful aids when equivalent accuracy is desired. Provided that the interval between consecutive values in the customary and the metric scale of the chart is kept similar, conversion of values by means of such charts will result in numbers that imply a practical degree of precision.

3.4.4 Magnitude and Precision

While a number is an abstraction and indicates a magnitude only in conjunction with a unit of measurement, it has been a long established convention in science and engineering to associate the precision of a measurement or measurement statement with the number of figures used to express the result.

Thus, while 2, 2.0, 2.00, and 2.000 <u>all</u> express a magnitude of "two" in relation to a reference unit, the precision of the numerical value is expressed to varying significant places of decimals. In the absence of any qualification, it has been normal practice to take the precision of a value as ±0.5 of the last significant place given; therefore, in the above expressions of the magnitude two, each statement is "more precise" than the preceding one.

The digits 1, 2, 3, ..., 9 are significant digits in terms of the precision of an expression. However, the digit 0 [zero] introduces considerable ambiguity. In a decimal context, the zero features prominently in preferred numbers [10, 100, 1000, 10 000, etc.], and it is not clear, how many zeros are significant. Does the number 10 000 indicate a precision of ±5000, ±500, ±50, ±5, or even ±0.5? Generally, the precision is a matter of knowing the full measurement context, and it cannot be inferred solely from a numerical statement.

This ambiguity is compounded further during metrication, when a conversion factor to five or six significant digits is used, and a value judgment is required to decide the "equivalent" precision of a metric value.

While it is counter-productive and misleading to show conversions to a large number of significant digits, it can be dangerous to apply excessive rounding or truncation in situations where mechanical interchangeability is required. Such rounding may introduce measurement values which fall outside acceptable tolerances for a customary product or characteristic when such an item is to be retained in the transitional period but to be expressed in SI units.

3.4.5 Rounding of Values

In general, converted values should be rounded to maintain a degree of precision similar to that implied in the original [customary] value. In the approach to rounding, it is desirable to obtain information on the following aspects:

[a] What is the inherent accuracy of the customary measurement statement?
[b] What tolerances are stated, or acceptable?
[c] What accuracy is necessary for functional reasons?
[d] What is the degree of precision with which measurements can be made?

For example, it would be futile to state an accuracy requirement to two places of decimals, if actual measurements can only be made to the nearest whole number.

Conventions for rounding have been established on the following basis:

[i] when the first digit to be discarded is <u>less than five</u> [<5], the last digit that is retained should not be changed; that is, the number is truncated at the last digit to be retained.

For example: If 3.5432 is to be rounded to four digits it will become 3.543;

if 3.5432 is to be rounded to three digits it will become 3.54; and,

if 3.5432 is to be rounded to two digits it will become 3.5.

[ii] when the first digit to be discarded is <u>greater than five</u> [>5], or five followed by at least one digit other than zero, the last digit retained should be increased by one unit; that is, the last digit retained will be rounded up.

For example: If 8.9876 is to be rounded to four digits it will become 8.988;

if 8.9876 is to be rounded to three digits it will become 8.99; and,

if 8.9876 is to be rounded to two digits it will become 9.0.

In the case of "rounding-up" a digit nine to the digit zero, the digit preceding the zero will be increased by one unit.

[iii] when the first digit to be discarded in <u>exactly five</u>, or five followed by zeros only, the last digit retained should be rounded upward if it is an odd number, and retained where it is an even number. However, in some instances involving preferred numbers, this convention may need to be disregarded.

For example: If 1.235 is to be rounded to three digits it will become 1.24;

if 1.245 is to be rounded to three digits it will also become 1.24;

however, if 1.25 is a preferred number in a series of preferred numbers, 1.245 could be rounded to 1.25.

When exact conversions are rounded to provide more workable values, it is suggested that a record be maintained of the <u>percentage difference</u> as well as the <u>absolute difference</u> [in terms of a reverse conversion] of the rounded value. To ascertain the most suitable new metric value where a number of decision alternatives exist, conversion alternatives may be tabulated in the manner suggested below, or any other appropriate matrix presentation.

For example: A reference value of <u>60 lbf/in^2</u> [psi] is to be converted. The conversion factor is: 1 lbf/in^2 [psi] = 6.894 76 kPa [kilopascals]. The exact conversion of 60 lbf/in^2 [psi] is <u>413.6856 kPa</u>.

<u>Schedule of Conversion Alternatives</u>

Rounded Metric Value	% Change +	% Change -	Reverse Conversion	Absolute Difference
413.7 kPa	+0.0035		60.002 psi	+0.002 psi
414 kPa	+0.076		60.046 psi	+0.046 psi
413 kPa		-0.166	59.901 psi	-0.099 psi
415 kPa	+0.318		60.191 psi	+0.191 psi
410 kPa		-0.891	59.465 psi	-0.535 psi
420 kPa	+1.526		60.916 psi	+0.916 psi
425 kPa	+2.735		61.641 psi	+1.641 psi
400 kPa		-3.308	58.015 psi	-1.985 psi

This example shows a variety of alternative metric values obtained by progressive rounding including preferred values that are both larger and smaller. It also indicates the change in the magnitude of the rounded metric value in both percentage terms and absolute terms. The percentage changes for the rounded values of 413, 414, and 415 are well below 0.5%; they could all be classed as a soft conversion. The more rounded values of 410 and 420 are below a percentage change of 1% and 2%, respectively. The preferred value 400 involves a percentage change of 3.3%.

But equally significant is the change in absolute terms indicated by the reverse conversion, as it provides a feel for the magnitude of the more rationalized metric alternatives in terms of customary measurement. The reverse conversion and the absolute difference indicate that quite a few metric values, which might be precluded by a percentage limitation in rounding, can come into serious contention. For example, where the measuring equipment can only show "actual" measurements to the nearest 1 psi, or 2 psi, in customary units, the substitution of a more rounded metric value for 60 psi may be quite in order, as this would represent an equivalent value within the indicated precision. In the examination of rounding possibilities more than one rounded value may appear to be acceptable. In such an instance, all alternatives should be shown in the conversion schedule to provide an optimum set of choices.

3.5 A Conversion Schedule for Use in Manual Conversion

The conversion of technical information to SI units is a priority item in the metrication program of the U.S. construction and engineering industries because no genuine metric work is possible without metric specifications, standards, codes and other technical data. The lead-time now available prior to a firm commitment to and timetable for the change ought to be utilized to effect most of the preparatory tasks needed in the conversion and rationalization of technical documents.

It is suggested that a standardized schedule be developed and used to identify and list all measurement sensitive requirements expressed in customary units, to describe characteristics [such as type of value, limits, and dependencies], to show the exact conversion, and to list alternative metric values together with their percentage variation and reverse conversion.

Such a schedule has the advantage that it provides a perspective to the "decision options," as well as a useful technical record of any conversion decisions that are taken.

A sample schedule has been developed for illustrative purposes only, and is shown in Table 10 on page 49. The three examples have been selected at random from three different building codes or standards, to illustrate different aspects of conversion.

The conversion schedule has five major parts:

- [i] item identification (chronological item number; page number, clause number);
- [ii] listing of the customary value;
- [iii] assessment of the characteristics (type of value; limits; dependencies)--shown by means of symbols for type of value and limits;
- [iv] exact conversion (shown to four or five significant digits, as appropriate); and
- [v] alternative rounded values (first and second alternative), together with their percentage variation and reverse conversion for comparison purposes.

Table 10 SAMPLE CONVERSION SCHEDULE FOR MANUAL CONVERSION OF TECHNICAL INFORMATION

EXAMPLE 1 NFPA National Fire Codes, Vol.1 [1977]- Standard for Portable Fire Extinguishers (NFPA No.10-1975)

ITEM NO.	PAGE NO.	CLAUSE NO.	CUSTOMARY VALUE	Type	Limit	Dependency	EXACT CONVERSION	ROUNDED VALUE	% Var.	REVERSE CONVERSION	ROUNDED VALUE	% Var.	REVERSE CONVERSION
5	10-8	1-4.8	40 pounds	GV	UL	[5 feet]	18.144 kg	18 kg	-0.8	39.68 lb	20 kg	+10.2	44.09 lb
6	10-8	1-4.8	5 feet	GV	UL	[<40 lb]	1524 mm	1500 mm	-1.6	4'-11.05"			
7	10-8	1-4.8	40 pounds	GV	LL	[$3^1/2$ feet]	18.144 kg	18 kg	-0.8	39.68 lb	20 kg	+10.2	44.09 lb
8	10.8	1-4.8	$3^1/2$ feet	GV	UL	[>40 lb]	1066.8 mm	1050 mm	-1.6	3'-5.34"	1100 mm	+3.1	3'-7.3"
9	10.8	1-4.8	4 inches	GV	LL		101.6 mm	100 mm	-1.6	3.94"			
10	10.8	1-4.11	+40°F	GV	LL		4.44°C	4°C		39.2°F	5°C		41°F
11	10.8	1-4.11	+120°F	GV	UL		48.89°C	49°C		120.2°F	50°C		122°F

EXAMPLE 2 The BOCA Basic Building Code 1975 [Sixth Edition] - Light and Ventilation

ITEM NO.	PAGE NO.	CLAUSE NO.	CUSTOMARY VALUE	Type	Limit	Dependency	EXACT CONVERSION	ROUNDED VALUE	% Var.	REVERSE CONVERSION	ROUNDED VALUE	% Var.	REVERSE CONVERSION
xxx	159	512.5	3 sq. feet	GV	LL	[S.925.3]	0.2787 m^2	0.27 m^2	-3.1	2.906 ft^2	0.3 m^2	+7.6	3.229 ft^2
xxy	159	512.6	every 12 min	GV	AV		[ev. 720 s]	5/h	0		(or le	ave as	is)
xxz	159	512.7	3 footcandles	GV	AV	[30 inches]	32.29 lx	32 lx	-0.9	2.97 fc	30 lx	-7.1	2.787 fc
xya	159	512.7	30 inches	GV	LL	[3 ft cdls]	762 mm	750 mm	-1.6	29.53"	700 mm	-8.1	27.56"

EXAMPLE 3 The ICBO Uniform Building Code [1976 Edition] - Dry Standpipes

ITEM NO.	PAGE NO.	CLAUSE NO.	CUSTOMARY VALUE	Type	Limit	Dependency	EXACT CONVERSION	ROUNDED VALUE	% Var.	REVERSE CONVERSION	ROUNDED VALUE	% Var.	REVERSE CONVERSION
yya	537	3803.d.1	300 psi	GV	UL		2.068 MPa	2.1 MPa	+1.5	304.6 MPa	2 MPa	-3.3	290 psi
yyb	537	3803.d.1	200 psi	GV	LL	[2 h test]	1.379 MPa	1.4 MPa	+1.5	203.1 MPa			
yyc	537	3803.d.1	50 psi	GV		[> max WP]	344.7 kPa	350 kPa	+1.5	50.76 kPa			
yyd	537	3803.d.2	$^1/4$ in to 10 ft	GV	AV		2.08 mm/m [1:480]	2 mm/m [1:500]	-4.2				

3.6 Rationalization of Metric Values in Technical Information

In addition to the rounding of numerical values, many instances will arise where it is desirable and, indeed, warranted to rationalize metric requirements. In this context, the term "rationalization" is meant to describe the change to an entirely "new" and differing set of values as the result of research and/or technical and economic considerations.

Rationalization, or the development of an optimum functional range, has already been described briefly in Sections 1.8 and 1.9. In technical information and production, rationalization may be used to accomplish one or more of the following:

- [a] to change a range of requirements to make them more compatible with actual needs or service conditions;
- [b] to change the distribution of values within a range to provide better increments or more suitable selection;
- [c] to reduce the number of alternatives within a range by means of rearrangement, deletion and/or substitution; and,
- [d] to harmonize differing requirements in existing technical data--particularly, standards and codes--dealing with identical subject matter or issues, to make design and production easier and to remove barriers to trade.

Rationalization is diametrically opposed to "soft conversions," and in nearly all cases provides superior solutions, especially in the longer term. To rationalize, it is necessary to critically examine all ranges, sets, or series of values in specifications, standards, codes, and other technical data, to determine whether it is feasible to substitute a more effective range, a smaller range, or a supplementary range during the transition to SI measurement.

It is generally easier to rationalize standards' requirements for design than it is to rationalize specifications for products, because the cost of manufacturing changes acts as an obstacle to the streamlining of product characteristics or variety reduction within the product line. However, international precedent in metrication shows many effective examples of such rationalization and variety reduction in the building and engineering products sector during the change to SI. The choice of simple and preferred numerical values will facilitate production processes, testing and verification, design and specification, assembly processes, and general identification. Typical examples can be found in rationalized metric ranges of thicknesses, diameters, areas, volumes, other geometrical properties, stresses, load factors, other structural properties, electrical properties, etc. While some amount of dimensional [modular] coordination was achieved in the customary measurement environment, there was never the catalyst of wholesale review to support the widespread change to preferred dimensions and sizes. The change to a new measurement system, SI, will only come once, and if it is not harnessed by the technological community and industry as a never-to-be-repeated opportunity for rationalization, one of the great opportunities of our era will have been squandered.

The techniques indicated in Section 3.7 have been developed to facilitate the decision-making processes that are required in rationalization by formalizing all required mathematical analysis in an automated approach.

3.7 A Format for an Automated Approach to the Selection of Preferred or Convenient Values in Technical Information

3.7.1 Overview

The timely preparation of metric technical documents, such as specifications, standards, codes, and other data, constitutes the largest and probably most significant task in the metric conversion program for the U.S. building and related engineering industries. In all other major English-speaking countries that have preceded the U.S. in metrication, quite a few years were allocated to the development of a comprehensive metric data bank. The tasks associated with conversion and rationalization of technical information, and the development of entirely new metric data, are time consuming and labor intensive. Because of the natural hierarchy of such data, where some information is dependent upon other and more fundamental information, a chronological approach is almost essential. Fundamental documents should be prepared before derived documents to avoid a conflicting selection of requirements and the possibility of early metric revisions, both of which would confuse information users.

This Section outlines an approach to metrication which can improve decision-making and save time in the development of data by the use of electronic data processing facilities. The approach is based on the assumption that computers can identify and scrutinize possible "preferred metric values" within reach of direct conversions of existing customary values, or within a range covered by existing customary values. Computers can be programmed to identify and rank preferred options [alternatives] with speed and accuracy, and, therefore, can provide accurate and helpful information on suitable metric alternatives.

The techniques outlined <u>will not select metric values</u>--they will simply respond to a sensitivity assessment and a program containing preferred and convenient number options by organizing the following tasks:

[a] the tabulation of a range [or set] of alternative values for various assigned variances and/or limitations;

[b] the ranking of the most preferred metric values in an order of preference; and,

[c] the demonstration, in percentage and absolute terms, of the quantitative changes associated with each nominated preference.

As a further refinement, the program may be expanded to permit the assessment of series of numerical values in addition to individual values. Such a feature is most useful where a reduction in the variety of alternatives is desired and where the required number of steps in a range can be nominated.

3.7.2 The Central Concept — Sensitivity Assessment

The methodology is based on a further assumption; namely, that customary values have been evolved and tested over a lengthy period and represent a reasonable approximation of desirable criteria, so that metric values ought to be similar or cover a similar range though not identical. The history of various building and engineering requirements, and of building product standardization has shown that measurement values are not static but subject to quite a few adjustments over time. Typical examples are: design rules for the use of steel or concrete; strengths of materials; cross-sectional areas and section properties of structural materials [steel, lumber]; ceiling heights in buildings; height and area limitations; levels of illumination, etc. The change to metric measurement will mean that quite a few minor adjustments will be made to arrive at preferred properties or characteristics.

The sensitivity assessment of existing values can be accomplished in two ways: either by attaching to each value an "index of criticality" as a measure of its "sensitivity to change;" or, by the assumption that metric replacement values will occur within a set of "sensitivity bands" which are a measure of progressively increasing variance. Both approaches lead to a similar conclusion, and in the search for preferred values, both approaches shift in their emphasis away from exact conversion and progressive rounding. In fact, the latter approach starts with preferred values rather than equivalents.

The technique requires a computer program with the following ingredients:

[a] a schedule of SI working units and conversion factors for each customary unit likely to be encountered in technical information;

[b] a conversion routine to determine exact equivalents as well as any set of programmed variances;

[c] a schedule of convenient and preferred numbers for general applications, and of preferred dimensions for linear measurement; and,

[d] a search routine to pinpoint and list preferred values within various sensitivity bands.

The output data would show:

[i] the conversion of the customary value to the SI equivalent;

[ii] the preferred value (or values) within a two-directional sensitivity spectrum [positive <u>and</u> negative variance permitted] or a one-directional sensitivity spectrum [positive variance <u>or</u> negative variance only];

[iii] the ranking of preferred values, where more than one preferred value exists;

[iv] the percentage change from the exact equivalent for each value listed; and,

[v] the reverse conversion of each value into customary units to provide an "absolute" comparison.

The use of an index of criticality in association with each measurement statement or group of measurement statements introduces an a priori limitation which curtails the maximum variance from the exact equivalent of a customary value that will be accepted.

The use of sensitivity bands provides a comprehensive mathematical analysis for all bands that are selected, and, therefore, defers any decisions as to which value is considered superior, although preferences may be ranked according to their occurrence in the spectrum of variances, starting from or terminating with the exact conversion.

The concepts are discussed in detail in Sections 3.7.3 and 3.7.4.

3.7.3 Index of Criticality

One approach to the conversion of technical data to SI units is to assign a grade or "index" of criticality to each value to indicate the degree of change that is considered acceptable. This notion of criticality is useful for all situations that do not involve mechanical interchangeability.

The following classification system is suggested:

Criticality Index A:	Exact conversion required within existing tolerances for reasons of mechanical interchangeability, or due to the use of an absolute value. [The use of Index A will be rare in technical information dealing with building design and construction, but is likely to occur in the transitional period in relation to some specific product characteristics.]
Criticality Index B:	Soft conversion with minor rounding, within an acceptable variance of ±1%; +1%; or, -1%, depending upon circumstances.
Criticality Index C:	Moderate rounding is permissible, within an acceptable variance of ±2%; +2%; or, -2%, depending upon circumstances. For most conversion situations involving linear measurement, preferred metric values will be found where a Criticality Index C is used.
Criticality Index D:	Significant rounding is permissible, within an acceptable variance of ±5%; +5%; or, -5%, depending upon circumstances.
Criticality Index E:	Substantial rounding is permissible, within an acceptable variance of ±10%; +10%; or, -10%, depending upon circumstances.
Criticality Index F:	No restraints exist; a suitable and preferred metric value may be selected to suit a particular application, without reference to any customary values.

The assignment of a criticality index to individual values in specifications, standards, codes, or other technical information, involves serious questioning and assessment of the following aspects:

[a] How was the customary value established initially? Was it as a result of:

- historical precedent? [If so, is such precedent still valid?]
- international precedent and/or the acceptance of overseas data? [If so, have such data been changed elsewhere? What are the accepted metric values?]
- use of a particular production technology?
- analysis and/or testing of prototypes?
- research into optimum conditions or an optimum value?
- preference for a simple numerical value?

Quite possibly, such questioning will show that most customary values were chosen on the basis of commonsense--namely, through the empirical knowledge of a suitable "range of acceptable values" and the choice of a simple reference value from such a range. Generally, there is no reason to consider customary values as immutable and resistant to change. It is recommended that an "acceptance range" for a metric replacement value be determined and the most suitable (or preferred) metric value be chosen from that range.

[b] Was the customary value changed over a period of time? If so, why?

Any changes that have been made to requirements or characteristics expressed in customary units may provide information about the past direction of modifications--such as increases or decreases in limits--as well as some useful arguments for the assignment of an index of criticality.

[c] How much "inbuilt" or "stated" tolerance is associated with the customary value?

In many instances, a significant variance is already permitted; for example, a permissible tolerance of [±] $^1/_4$" in a stair tread of 10" represents a variance of ±2.5%.

[d] Are there any research results, technical and/or economic considerations that will have a modifying effect on customary values?

Quite a few occasions are likely to arise where the change to metric [SI] units can be coupled with a necessary or desirable review and modification of requirements or sizes. For example, the energy conservation requirements induced by economic factors and the associated need for increased thermal insulation in framing members may necessitate a change in cross-section of structural framing materials, such as lumber or metal sections. The opportunity arises to combine size changes with a change to preferred metric dimensions.

[e] Are there relevant precedents among existing international standards?

- Are international standards expressed in metric units relevant?
- Would the acceptance of an "international value" assist U.S. industry, or be detrimental?
- In view of the similarities in building and engineering technology, does the current metrication program in Canada provide any useful guidance?

[f] Are there any factors which inhibit the change to preferred metric values? If so, is this because:

- "metric" preferences have not yet been established?
- legal requirements "demand" a particular value or magnitude?
- decisions on preferences lie outside the control of the organization preparing metric technical information?

Finally, the question arises whether or not it is possible to introduce a "general criticality index" for certain physical quantities. For example, the acceptance of a General Criticality Index C [±2%] for linear measurement in building would permit the use of preferred metric dimensions in nearly all instances, as the basic building module [M] of 100 mm is only 1.6% less than 4 inches; similarly, 300 mm is 1.6% less than 1 foot, 900 mm is 1.6% less than 1 yard, 3000 mm is 1.6% less than 10 feet, etc. The widely used surveying dimension of 1 chain (66 feet) is only 0.6% longer than 20 meters; the same holds for 1 furlong (10 chains, or 660 feet, or 220 yards), which is just 0.6% longer than 200 meters.

In some countries that have preceded the United States in metrication, legislators have permitted a variance approach in legislation during the transitional period, by delegation of authority to make changes up to a specified percentage variance from customary values under an "Omnibus Act." A typical example of this approach is given in this statement from an Act of the State of Victoria, Australia: "...... a physical quantity expressed in a system other than the metric system may be amended by regulation by substituting a reference in metric units provided the quantity is not thereby changed by more than 12.5 percent ....".

The Australian experience with this approach has demonstrated that the selection of preferred metric values becomes very much easier when there is an "a priori" decision to permit the change of requirements or reference values by legislative authority. However, the question of "criticality" still needs to be asked either before conversion and rounding are undertaken, or after a direct conversion and prior to any rounding and/or rationalization.

The criticality points suggested in this Section [±1%; ±2%; ±5%; and, ±10%] have been chosen simply for ease of calculation--1% and 10% can be obtained directly, merely by shifting the decimal point two places or one place to the left, while 2% and 5% can be determined by doubling 1%, or by halving 10%, respectively. Alternative criticality points may be selected; for example, it may be more appropriate to progressively double the variance, such as 1%, 2%, 4%, 8%, 16%, etc.

3.7.4 Sensitivity Bands

The concept of "sensitivity bands" is founded on the notion that preferred metric replacement values for any customary value can be found within a set of progressively widening variance ranges which are associated with the direct equivalent of a customary value.

Mathematically, the relationship of any preferred metric value [y] to the exact equivalent of a customary value [a] can be expressed by the function: $y = a \pm ax$, where x is the percentage variance. For simple variance limits of +1%, +2%, +5%, and +10%, the limiting values for y become: 1.01a, 1.02a, 1.05a, and 1.1a; for variance limits of -1%, -2%, -5%, and -10%, the limiting values become: 0.99a, 0.98a, 0.95a, and 0.9a. This makes it possible to construct the following sensitivity bands:

Sensitivity Band 1 [SB±1 (Range 0.99a - 1.01a); SB+1 (Range 1.0a - 1.01a)]
SB-1 (Range 0.99a - 1.0a)]

Sensitivity Band 2 [SB±2 (Range 0.98a - 1.02a); SB+2 (Range 1.0a - 1.02a)]
SB-2 (Range 0.98a - 1.0a)]

Sensitivity Band 5 [SB±5 (Range 0.95a - 1.05a); SB+5 (Range 1.0a - 1.05a)]
SB-5 (Range 0.95a - 1.0a)]

Sensitivity Band 10 [SB±10 (Range 0.9a - 1.1a); SB+10 (Range 1.0a - 1.1a)]
SB-10 (Range 0.9a - 1.0a)]

The numeral associated with SB indicates the percentage variance, and the sign the direction of the variance.

An additional Sensitivity Band 20 [SB±20 (Range 0.8a - 1.2a); SB+20 (Range 1.0a - 1.2a); and, SB-20 (Range 0.8a - 1.0a)] may be useful in special circumstances to ascertain whether any preferred metric values can be found outside a 10% variance.

Sensitivity bands may also be used graphically within a coordinate system that uses a metric as well as a customary unit scale on the y-axis so that preferred metric values as well as reverse conversions can be determined. The functions <u>y = a + ax</u> and <u>y = a - ax</u> form a wedge or funnel with the value <u>y = a</u> as origin. For a one-directional sensitivity--that is, a positive or negative variance only--preferred metric values will be found on one of the functions only. The sensitivity bands establish variance ranges on the x-axis.

An actual example of the use of sensitivity bands to determine alternative preferred metric values is shown in Figure 4. The figure shows a two-directional [±] variance for a reference value of 27.597 MPa, the conversion of 4000 lbf/in^2 [psi]. The two functions which intersect in the reference value are: $y = 27.597 + 0.275\ 97\ x$ and $y = 27.597 - 0.275\ 97\ x$.

<u>Figure 4</u> <u>TWO-DIRECTIONAL SENSITIVITY BANDS [POSITIVE AND NEGATIVE VARIANCE]</u>

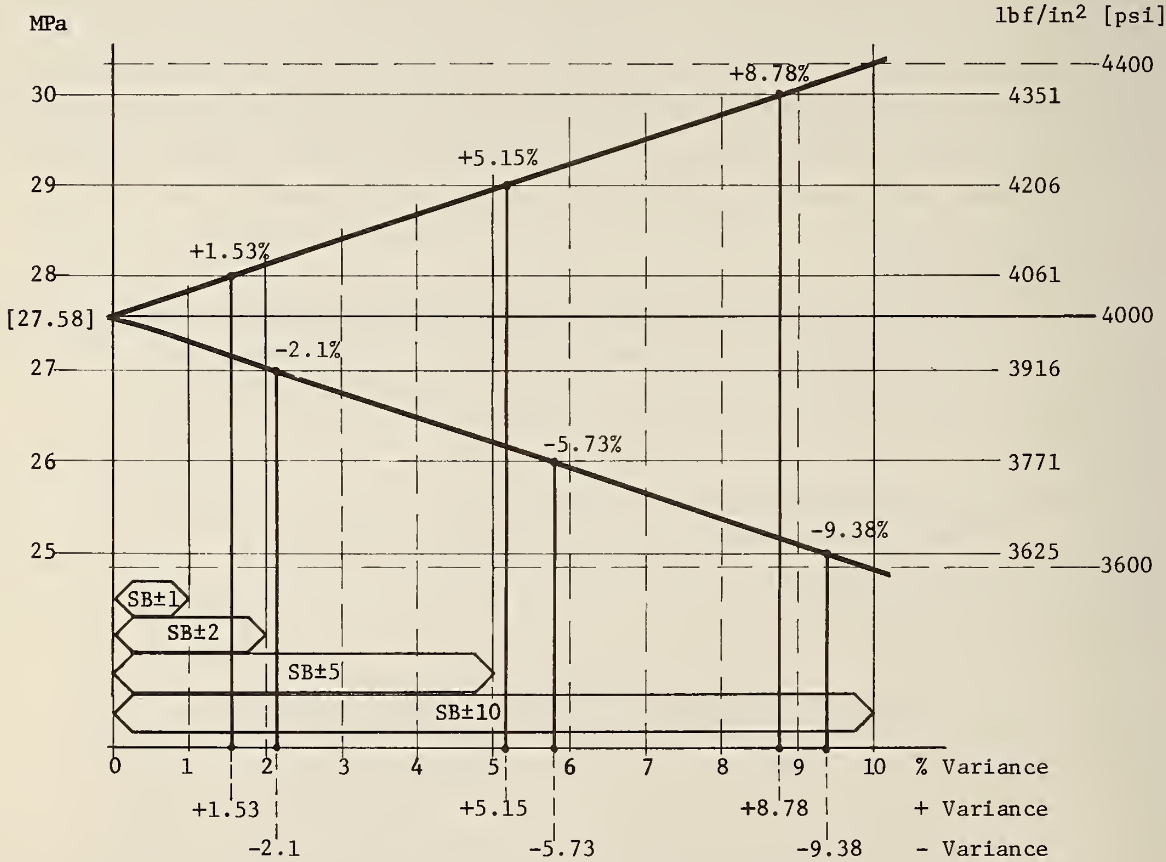


Figure 4 shows graphically that no integer [whole number] occurs within Sensitivity Band 1; that one integer (28) occurs within Sensitivity Band 2; that two integers (27 and 28) occur within Sensitivity Band 5; and, that all integers between 25 and 30 (25, 26, 27, 28, 29, and 30) occur within a ±10% variance.

Figure 4 can also be used to demonstrate which preferred metric values occur within a one-directional [+ <u>or</u> -] sensitivity band, by taking only those values which occur in the upper (positive) or lower (negative) function.

A computer can be programmed to prepare a graphic output of variance analysis in which the preferred metric alternatives are highlighted.

As indicated for criticality points in Section 3.7.3, different ranges may be assigned to the sensitivity bands; for example, the permissible variance may be doubled in successive bands, such as SB1, SB2, SB4, SB8, and SB16.

3.7.5 Advantages of Sensitivity Bands

Sensitivity assessment of numerical values in conversion situations by means of preselected sensitivity bands is especially useful where it can be coupled with a mathematical program and mechanized techniques of computation. It has the following advantages:

[a] it minimizes ad hoc decisions;

[b] it steers the choice of metric values towards "preferred" numbers and away from "soft conversions;"

[c] it provides a printed and/or graphic record of decision alternatives;

[d] it immediately demonstrates the effect of any numerical decision [selection] in terms of a percentage change from the customary value, as well as in absolute terms of the reverse conversion to customary units and the absolute difference expressed in customary units; and,

[e] it provides organized information only, but leaves the final selection of the most suitable value to those with the responsibility for that selection.

Sensitivity assessment by means of sensitivity bands is particularly valuable when a range of values is under examination, and a metric set or series with an equal number of terms or fewer terms is under consideration. The analysis can be performed either in tabular [matrix] form or in a graphic form.

3.7.6 An Example of the Use of Sensitivity Bands to Compare Metric Alternatives

Various possibilities in the choice of preferred number series have already been illustrated in Sections 2.5.10 and 2.5.11. The example of compressive strengths of concrete at 28 days has been mentioned on page 35, and this example can be studied in more detail. If the range of strengths under consideration is confined to the selection of possible substitutes for the customary arithmetic series of 7 terms: 2000, 2500, 3000, 3500, 4000, 4500, and 5000 psi, then the limits for the Sensitivity Bands SB±1, SB±2, SB±5, and SB±10 can be set out in matrix form:

Customary Value [psi]		2000	2500	3000	3500	4000	4500	5000
Metric Equivalent [MPa]		13.79	17.24	20.68	24.13	27.58	31.03	34.47
Sensitivity Band 1	[+1]	13.65	17.06	20.48	23.89	27.30	30.72	34.13
	[-1]	13.93	17.40	20.89	24.37	27.86	31.34	34.82
Sensitivity Band 2	[+2]	13.51	16.89	20.27	23.64	27.03	30.41	33.78
	[-2]	14.06	17.58	21.10	24.61	28.13	31.65	35.16
Sensitivity Band 5	[+5]	13.10	16.38	19.66	22.92	26.20	29.48	32.75
	[-5]	14.48	18.10	21.72	25.34	28.96	32.58	36.20
Sensitivity Band 10	[+10]	12.41	15.51	18.62	21.72	24.82	27.92	31.03
	[-10]	15.17	18.96	22.75	26.54	30.34	34.13	37.92

Based on convenient number preferences (Section 2.3), preferred numerical values from each sensitivity band can now be selected and ranked according to their preference.

Exact Conversion MPa [psi]	Soft Conversion Sensitivity Band ±1	Soft Conversion Sensitivity Band ±2	Whole Numbers Sensitivity Band ±5	Whole Numbers Sensitivity Band ±10
13.79 [2000]	13.8	14	14	15, 14, 13
17.24 [2500]	17.2	17, 17.5	18, 17	18, 17, 16
20.68 [3000]	20.5	21, 20.5	20, 21	20, 22, 21, 19
24.13 [3500]	24	24, 24.5	25, 24, 23	25, 24, 26, 22, 23
27.58 [4000]	27.5	28, 27.5	28, 27	30, 25, 28, 26, 27, 29
31.03 [4500]	31	31, 31.5	30, 32, 31	30, 32, 34, 28, 31, 33, 29
34.47 [5000]	34.5	35, 34, 34.5	35, 36, 34, 33	35, 36, 34, 32, 33, 37

If a metric replacement range with 7 term values and regular increments had to be selected, such values would approximate a soft conversion--14, 17.5, 21, 24.5, 28, 31.5, and 35. Irregular increments result if whole numbers [integers] are selected--14, 17, 21, 24, 28, 31, and 34 [or 35]. A similar range can be covered more effectively with an arithmetic or geometric series of 6 or fewer term values, but this would require definite product changes.

The following number series occur within a maximum variance of 10 percent from the direct equivalents of customary values:

	6 Term Values	5 Term Values	4 Term Values
Arithmetic Series:	14, 18, 22, 26, 30, 34	15, 20, 25, 30, 35	14, 21, 28, 35
Geometric Series:	R'40/3 (14....34) 14, 17, 20, 24, 28, 34	R'20/2 (14....36) 14, 18, 22, 28, 36	R'10 (16....32) 16, 20, 25, 32
	R'40/3 (15....36) 15, 18, 21, 25, 30, 36	R"20/2 (14....35) 14, 18, 22, 28, 35	R40/5 (15....36) 15, 20, 26, 36

It is possible to develop other number series to cover an equivalent range, and data processing techniques can be applied to identify the above and other series. However, with the exception of the arithmetic series--15, 20, 25, 30, and 35 MPa--none of the series shown have a similar numerical simplicity to that of the customary term values which were obviously selected with such simplicity in mind. Therefore, an arithmetic series with a 5 MPa interval between 15 MPa and 35 MPa may provide a suitable metric alternative, even though some of the traditional strength grades are deleted. The maximum variance from customary values is 8.8% (or 176 psi), as indicated in the variance analysis below. This analysis also shows the reverse conversion of metric values and the absolute difference.

Metric Value (MPa)	% Variance (from next lower customary value)	% Variance (from next higher customary value)	Reverse Conversion (psi)	Absolute Difference (psi)
15	+ 8.8 (13.79)	[-13.0] (17.24)	2176	+176 [-324]
20	[+16.0] (17.24)	- 3.3 (20.68)	2901	[+401] -99
25	+ 3.6 (24.13)	- 9.4 (27.58)	3626	+126 -374
30	+ 8.8 (27.58)	- 3.3 (31.03)	4351	+351 -149
35	+ 1.5 (34.47)		5076	+76

The variance analysis indicates a maximum absolute difference of 176 psi.

All the decision information can be shown in a single matrix, suitable for use with electronic data processing facilities. The example discussed has been used to develop such a matrix, as shown below:

Table 11 SAMPLE MATRIX SHOWING SENSITIVITY ANALYSIS FOR A RANGE OF VALUES

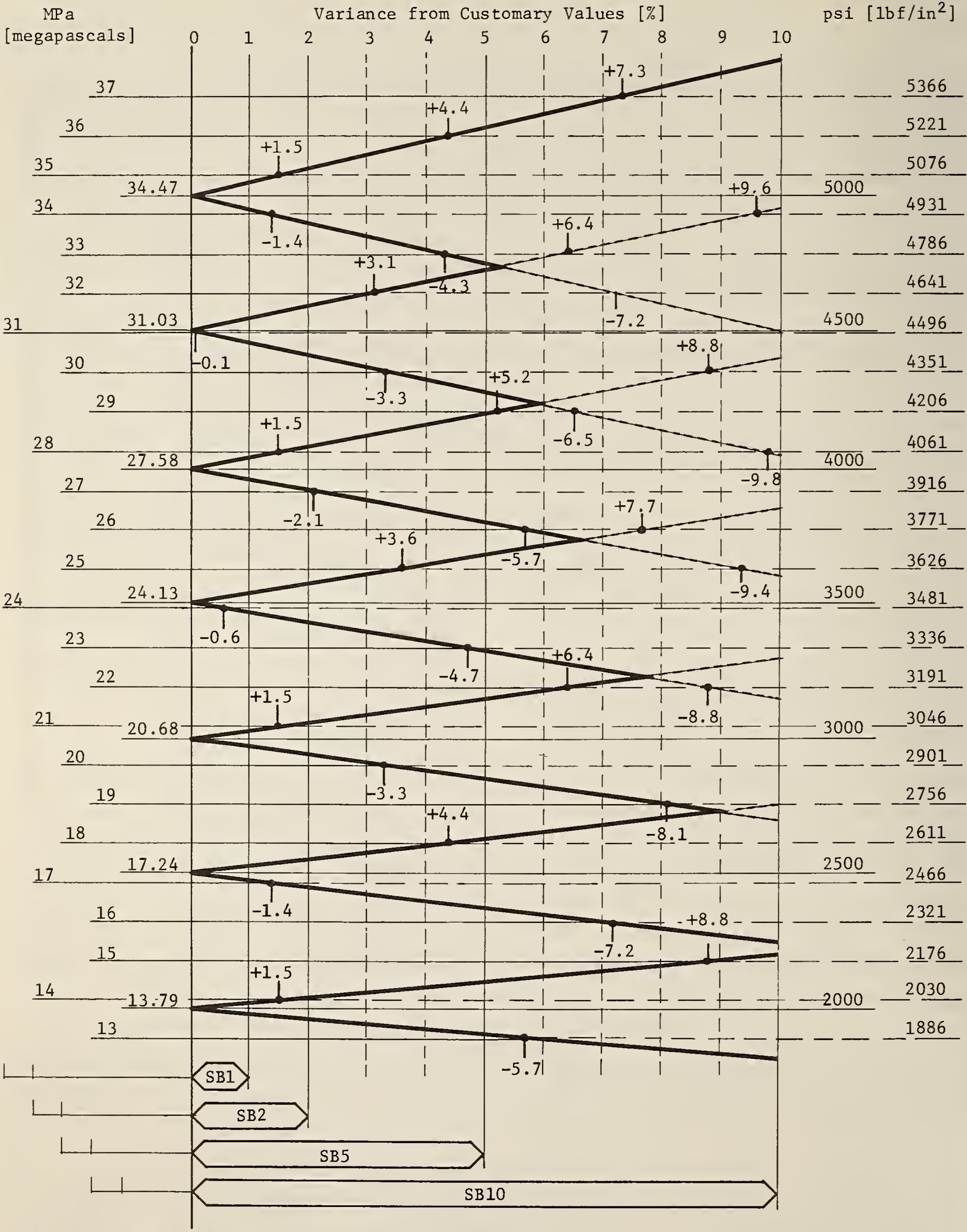
Customary Value [psi]	Exact Conversion [MPa]	SB1 ±1% Variance	SB2 ±2% Variance	SB5 ±5% Variance	SB10 ±10% Variance	Whole Number Metric Values		% Variance	Reverse Conversion [psi]	Absolute Difference [psi]
2000	13.79	13.65	13.51	13.10	12.41	13	SB10	-5.7	1886	-114
		13.93	14.06	14.48	15.17	14	SB2	+1.5	2030	+ 30
						15	SB10	+8.8	2176	+176
2500	17.24	17.06	16.89	16.38	15.51	16	SB10	-7.2	2321	-179
		17.40	17.58	18.10	18.96	17	SB2	-1.4	2466	- 34
						18	SB5	+4.4	2611	+111
3000	20.68	20.48	20.27	19.66	18.62	19	SB10	-8.1	2756	-244
		20.89	21.10	21.72	22.75	20	SB5	-3.3	2901	- 99
						21	SB2	+1.5	3046	+ 46
						22	SB10	+6.4	3191	+191
3500	24.13	23.89	23.64	22.92	21.72	22	SB10	-8.8	3191	-309
		24.37	24.61	25.34	26.54	23	SB5	-4.7	3336	-164
						24	SB1	-0.6	3481	- 19
						25	SB5	+3.6	3626	+126
						26	SB10	+7.7	3771	+271
4000	27.58	27.30	27.03	26.20	24.82	25	SB10	-9.4	3626	-374
		27.86	28.13	28.96	30.34	26	SB10	-5.7	3771	-229
						27	SB5	-2.1	3916	- 84
						28	SB2	+1.5	4061	+ 61
						29	SB10	+5.2	4206	+206
						30	SB10	+8.8	4351	+351
4500	31.03	30.72	30.41	29.48	27.92	28	SB10	-9.8	4061	-439
		31.34	31.65	32.58	34.13	29	SB10	-6.5	4206	-294
						30	SB5	-3.3	4351	-149
						31	SB1	-0.1	4496	- 4
						32	SB5	+3.1	4641	+141
						33	SB10	+6.4	4786	+286
						34	SB10	+9.6	4931	+431
5000	34.47	34.13	33.78	32.75	31.03	32	SB10	-7.2	4641	-359
		34.82	35.16	36.20	37.92	33	SB5	-4.3	4786	-214
						34	SB2	-1.4	4931	- 69
						35	SB2	+1.5	5076	+ 76
						36	SB5	+4.4	5221	+221
						37	SB10	+7.3	5366	+366

The matrix indicates all whole number metric values, the sensitivity bands in which they occur, the percentage variance, the reverse conversion, and the absolute difference of the metric value from the customary value, expressed in customary units. A program for the identification of series of numbers can be used to identify all number series which occur within a sensitivity band of, say, ±5% or ±10%.

The analysis can also be performed in a graphic form, similar to Figure 4 on page 56, but showing a whole range of values. Figure 5, on page 60, provides a simulated graphic display.

The selection of an appropriate series is a matter for an industry decision through the appropriate standards committee. The selection should be made to reflect the optimum response to marketplace conditions.

Figure 5 GRAPHICAL REPRESENTATION OF VARIANCES FOR METRIC VALUES [WHOLE NUMBERS]



The graphical representation shows that 24 and 31 MPa occur within SB1; that 14, 17, 21, 24, 28, 31, 34, and 35 MPa occur within SB2; and that all whole numbers are found within a maximum variance of ±8.8%.

3.8 The Basis for Numerical Selection by Automated Processes — The Categorization of Physical Characteristics of Measurement Statements in Relation to a Catalog of Number Preferences

To permit the mechanization of the selection of preferred metric alternatives, it is suggested that measurement statements be assigned to different categories or groups according to the physical characteristics under consideration, and that such categories be matched against the different number systems outlined in this report.

A distinction needs to be made between two types of measurement statements:

[i] Quantities used to describe physical sizes; and,

[ii] Quantities used to identify other physical properties.

Physical sizes include descriptions by means of linear measurement, area, volume, capacity (liquid volume), and mass; and such sizes can be distinguished visually, as well as by means of measurement. Other physical properties cannot be distinguished visually, but can be verified by measurement.

In the conversion of building and engineering specifications, standards, codes, and associated technical data, the greater portion of measurement sensitive statements deals with linear measurement in the form of requirements for length, width, height, depth, thickness, diameter, etc. Many of these linear dimensions have, or may have, an impact on the coordination of dimensions in buildings, structures, or equipment. Linear dimensions can be categorized in three categories:

Category A: Linear dimensions--for use with metric dimensional coordination

Category B: Independent linear dimensions--not part of a set or series

Category C: Related linear dimensions--which form, or may form, a set or series

In some situations, linear dimensions have a direct relationship to preferences for area, volume, or mass measurement.

Area measurement, such as area of cross-section, volume measurement including liquid volume, and mass measurement, can be used as "size identifiers," and will often require a simple progression of sizes involving sets or series of numbers which identify the ratios between different sizes. [For example, packaging may be in a progression of sizes, such as 1 kg, 2 kg, 5 kg, 10 kg, 20 kg; or, 250 mL, 500 mL, 1 L (1000 mL), 2 L (2000 mL), etc.] Therefore, size characteristics other than linear measurement can be divided into two categories:

Category D: Area, volume, or mass--independent values

Category E: Area, volume, or mass--related values which form part of a set or series

Conversion and rationalization will also extend to a wide variety of other quantities which are expressed predominantly by derived units, such as force, pressure and stress, bending moment, torque, mass density, energy, work and heat, power, heat flow, thermal conductivity, illuminance, etc. Again, these characteristics can be divided into two categories:

Category F: Derived Quantities--independent values

Category G: Derived Quantities--related values which form part of a set or series

The concepts of a sensitivity assessment by means of a variance approach cannot be applied to temperatures, because the scalar 0 [zero] for metric and U.S. customary units does not coincide, thus voiding a percentage comparison of relative magnitudes. Convenient and whole numbers should be selected during the change to SI, wherever practicable. The conversion of measurement statements involving temperature, therefore, forms an additional category:

Category H: Temperatures--independent values and sets of values

There is a wide range of measurement units in use with the U.S. customary system which are already in SI terms and do not require conversion. This group includes all units used in the field of electricity and electromagnetism, and luminous intensity as well as luminous flux.

While the traditional units for the measurement of time and angle will be largely retained, there may be some instances where it is preferable to express magnitudes in SI units; for example, by changing statements involving the time unit "minute" to statements containing the SI base unit "second," which will introduce an additional factor. An additional category can be introduced to cover such situations:

Category J: Time and Angle--substitution of SI units and preferred values

Using the preferred and convenient number systems discussed in Part 2, it now becomes possible to assign to each category a hierarchy of number system preferences. This makes it possible to utilize an automated approach to the identification and listing of preferred numerical values for all types of measurement statements, based on a matrix of preferences shown in Table 12.

Table 12 MATRIX OF PREFERENCES IN THE SELECTION OF METRIC VALUES FOR VARIOUS QUANTITIES

Category of Measurement Quantity	Convenient Numbers (2.3)	Preferred Dimensions (2.4)	Preferred Number Series		
			Arithmetic Series (2.5.2)	ISO-R Series (2.5.5-9)	ISO R3 Series [1-2-5 Series] (2.5.4)
A: Linear Dimensions--for use with metric dimensional coordination	3	1	2	-	-
B: Independent Linear Dimensions	1	2	3	-	-
C: Related Linear Dimensions--part of a set or series	3	-	2	1	-
D: Area, Volume, Mass--independent values	3	-	2	-	1
E: Area, Volume, Mass--related values, part of a set or series	-	-	2	3	1
F: Derived Quantities--independent values	1	-	2	-	3
G: Derived Quantities--related values, part of a set or series	3	-	2	1	-
H: Temperature values	1	-	2	-	-
J: Time and Angle	1	-	-	-	-

3.9 The Ingredients of an Automated Approach to the Selection of Preferred Metric Values

3.9.1 Overview

The automation of numerical analysis of preferred metric alternatives has five components:

[i] Preliminary Decisions

[ii] Preparation of a Core Program for Electronic Data Processing

[iii] Preparation of Input Data

[iv] Preparation of a Format for Output Data

[v] Use of Output Data in Decision-making

The bulk of the techniques and approaches needed in the determination of metric preferences which have been discussed in this report would be utilized in an automated [computer based] approach to the selection of preferred numerical values during metrication.

The five activity components have been broken down into specific activities, each of which has been cross-referenced to the appropriate Section of this report where it is discussed in greater detail.

3.9.2 Preliminary Decisions

The following preliminary decisions are required in the conversion and rationalization of technical information:

[a] Identification of all measurement sensitive statements (Section 3.2)

[b] Determination of the type of numerical value (Section 3.3.1)

i. for accurate [exact] values: use exact conversion and minimal rounding

ii. for designated [nominal] values: use [maximum/minimum] permissible values

[c] Determination of Acceptance Limits (Section 3.3.2)

[d] Assessment of whether the value is, or could become, part of a set or series and determination of the type of series (Section 2.5)

[e] Determination of Dependencies (Section 3.3.3)

i. effect of conversion and rationalization <u>on</u> other dependent values

ii. effect of conversion and rationalization <u>of</u> other values on the value under consideration

[f] Decision on the most suitable type of numerical analysis

i. a priori determination of an index of criticality (Section 3.7.3)

ii. use of sensitivity bands and deferral of selection of values (Section 3.7.4)

3.9.3 Preparation of a Core Program for Electronic Data Processing

The following items need to be considered for use in a conversion/rationalization program:

[a] Preparation of a comprehensive list of SI working units <u>and</u> conversion factors for all building and engineering related quantities

[b] Development of conversion and rounding subroutines

[c] Transcription of number selection systems:

i. Convenient numbers (Section 2.3)

ii. Preferred Linear Dimensions (Section 2.4)

iii. Sets or Series of Preferred Numbers

- o arithmetic series of convenient numbers (Section 2.5.2)
- o geometric series of numbers (Section 2.5.3)
- o special purpose 1-2-5 series (Section 2.5.4)
- o ISO preferred number series (Sections 2.5.6 - 2.5.10)

[d] Development of a subroutine for variance analysis

i. for a preselected index of criticality (Section 3.7.3)

ii. for a range of sensitivity bands (Sections 3.7.4 - 3.7.6)

[e] Development of a subroutine for the listing of alternatives where more than one preferred value occurs within a sensitivity band (Section 3.7.6)

[f] Development of an auxiliary program for graphical presentation of sensitivity bands and variances (Figure 5, page 59)

3.9.4 Preparation of Input Data

The following items need to be considered in the preparation of input data:

[a] Assignment of an identification to each measurement sensitive statement for purposes of data retrieval or cross-referencing (Section 3.2)

i. by means of chronological numbering

ii. by means of page and/or clause numbers

[b] Listing of customary values (Section 3.2)

[c] Identification, by means of coding, of the type of [customary] value (Section 3.3.1)

[d] Specification of limitations (Section 3.3.2)

i. positive variance for values with an upper limit

ii. negative variance for values with a lower limit

iii. positive and negative variances for mean values or values with a wide acceptance limit

[Note: The specification of a general index of criticality (Section 3.7.3) would make this step redundant.]

[e] Categorization of measurement statements (Section 3.8)

3.9.5 Preparation of a Format for Output Data

Output data can be presented in tabular [matrix] form, or, in the case of sensitivity analysis, in graphical form. Either approach will need to include the significant decision data.

Where an "a priori" limitation is imposed on the search range--by virtue of the choice of an index of criticality--the output data will show <u>only</u> the preferred value or values within the range covered by the index. Where sensitivity bands are chosen, a considerable number of alternatives may need to be ranked and tabulated; for example, there are 6 whole number metric alternatives [32, 33, 34, 35, 36, and 37 MPa] within a ±10% variance of a customary value of 5000 psi, and the output data need to be structured in a manner that will pinpoint the more/most desirable alternative(s).

The following output data should be included in a schedule:

[a] Item identification (Section 3.2)

[b] Customary value(s)

[c] Exact conversion, to at least 4 significant digits

[d] Category of value (Section 3.8)

[e] Identification of variance range(s) or limitation(s)

  i. for a predetermined index of criticality; or,

  ii. for selected sensitivity bands

[f] Tabulation of preferred numerical value(s) from the range

  i. in order of preference; or,

  ii. in order of occurrence

[g] Statement of the actual variance of preferred metric values in percentage terms [percentage difference]

[h] Reverse conversion of the preferred metric value into customary units and identification of the absolute difference for comparison purposes

[Note: The use of the conversion factor in reverse will lead to decimalization of many customary units; for example, the reverse conversion of 3600 mm would be indicated as 11'-9.732" rather than 11'-9 $^{47}/_{64}$".]

[i] Indication of any dependencies for the purpose of cross-referencing of the impact of any numerical selection.

This report includes sample schedules of output data for illustrative purposes only (Table 10, page 49; Table 11, page 59; and, Appendix D, page 73).

3.9.6 Use of Output Data in Decision-making

The group or committee responsible for the conversion and numerical rationalization of specifications, standards, codes, and other technical information can use automated output data in the following manner:

1. to select the most appropriate metric value or set of values by means of a comparison and assessment of the preferences indicated in tabular or graphical form;

2. to check the effect(s) of such selection(s) against any of the dependencies indicated; for example, how will the choice of a preferred linear dimension affect spans, spacings, loadings, deflection, or other properties;

3. to check the effect(s) on the selected value of conversion and rationalization of other values; that is, will the choice of a rationalized value in another part of a document, or in a related document, have any modifying effect on the selected value; and,

4. to repeat, if necessary, the routine with new limits; for example, a different index of criticality or a change in variance.

3.10 Concluding Remarks

The use of a methodology, such as that outlined in this report, does not make decisions for those responsible for the conversion and rationalization of technical information--it will merely formalize the decision processes, widen the choice of alternatives, prevent oversights and mathematical errors, and generally speed up the process of metrication. The ultimate choice should always be made to reflect market conditions as well as numerical preferences.

APPENDIXES

APPENDIX A: GLOSSARY OF TERMS

In the context of this report, the following definitions have been assigned to various terms:

accuracy	the degree of conformity of a measured or calculated value to some recognized standard or specified value -- *see also precision* [accuracy refers to the correctness of a dimension or value]
amount	magnitude
conversion	change from one state to another
metric conversion	change to metric [SI] units -- also referred to as "metrication"
criticality	critical quality or state, involving a transition point
decimal	of, or based upon the number ten; progressing by ten
decimal system	a number system using the base ten
decimal place	a position [place] in a decimal system indicating a positive or negative power of ten
digit	one of the ten Arabic numerals (0, 1, 2, 3, 4, 5, 6, 7, 8, 9)
significant digit	any digit that is necessary to define the value of a quantity
exactness	*see precision*
figure [numerical]	an arithmetic value expressed by one or more digits
fraction	the indicated quotient of one expression divided by another
common fraction	a fraction in which the numerator and denominator are integers
decimal fraction	decimal part; the expression of a fraction in decimal notation *(Note: Some common fractions expressed in decimal notation result in infinite decimal expressions and will need to be rounded or truncated.)*
integer	an arithmetic term for a whole number
magnitude	extent of a quantity; a number assigned to a quantity according to a stated rule which makes it possible to compare that quantity with others
number	a symbol, or group of symbols, showing either "how many" or "what place in a sequence"
rational numbers	all integers and common fractions
numeral	a symbol, figure, letter, or word noting a number or numbers
Arabic numerals	figures used as numerals (0, 1, 2, 3, 4, 5, 6, 7, 8, 9)
Roman numerals	selected Roman letters used a numerals (I, V, X, L, C, D, M)
optimization	an organized activity to secure maximum efficiency
catalog optimization	the planned arrangement of a catalog (of elements or products) to secure the most efficient [cost effective] range
precision	the degree of mutual agreement between individual measurements, namely repeatability and reproducibility -- *see also accuracy* [precision refers to refinement of measurement]
preference	one that is preferred because of advantages over others
preferred number	a number specifically preferred over others *(Note: The term "preferred number" has been assigned a specific meaning by the International Organization for Standardization (ISO), namely, to describe the conventionally rounded off term value in the Renard series, including the integral powers of ten of such numbers)*
quantity	a measurable or numerable amount; a particularized magnitude
physical quantity	a measurable attribute of a physical phenomenon, measured by means of the appropriate SI reference unit and a number which indicates the magnitude in relation to the reference quantity

reference quantity	a precisely defined physical quantity which establishes a unit standard
rationalization	an organized activity, based upon an orderly approach or system, to avoid duplication or waste, simplify procedures, coordinate diverse parts, etc.
sensitivity	quality or state of being highly responsive with respect to change of measured or calculated quantities
series	an orderly progression [set] of numbers connected by a mathematical rule
arithmetic series	a series, each of whose terms is derived from the preceding term by the addition of a constant value
geometric series	a series, each of whose terms is derived from the preceding term by the multiplication of a constant factor [or ratio]
Renard series	a series, denoted by the abbreviation R, used in standardization which is characterized by conveniently rounded-off terms of a geometric series with originating and terminating values that are powers of ten
set	a collection of mathematical elements which belong together or are used together
value	the amount or extent of a specified measurement of a physical quantity; a particular quantitative determination
approximate value	a value that is nearly, but not exactly, correct or accurate
designated value [or nominal value]	a value assigned for the purpose of convenient designation or description only, thus existing in name only
numerical value	a combination of a number and a reference unit
variance	variation, or a specific degree of such; divergence.
zero	the arithmetical symbol 0, denoting the absence of all magnitude or quantity; the number between the set of all negative numbers and the set of all positive numbers.

APPENDIX B: THE APPLICATION OF PREFERRED NUMBER SERIES IN INTERNATIONAL STANDARDS

Example 1 - Use of the R5 and R10 Series:

Australian Standard AS 1256 - 1973 "Preferred Metric Sizes of Hot Rolled Flat Steel Bars and Wrought Non-ferrous Rectangular Bars"

TABLE 2 - COPPER RECTANGULAR BARS (page 5)

Width mm	Thickness mm				
12.5	2.5				
16	2.5	4			
20	2.5	4			
25	2.5	4	6.3		
31.5	2.5	4	6.3		
40	2.5	4	6.3		
50	2.5	4	6.3	10	
63	2.5	4	6.3	10	
80		4	6.3	10	
100		4	6.3	10	16
125			6.3	10	16
160			6.3	10	16

Comments

Widths for Copper Rectangular Bars are taken directly from R10 (12.5......160)

Thicknesses for Copper Rectangular Bars are taken directly from R5 (2.5......16)

The table lists 35 combinations of width and thickness.

Example 2 - Use of the R'10 Series [with rounding to provide whole numbers]:

British Standard BS 4461 : 1969 "Cold Worked Steel Bars for the Reinforcement of Concrete"

(page 5)

TABLE 1. PREFERRED SIZES

Nominal size	mm	6	8	10	12	16	20	25	32	40

Comments

Metric cold worked steel bars for the reinforcement of concrete form a new series, differing from the traditional [Imperial] bars.

Nominal sizes are taken from R'10 (8.....40) with the change of the 12.5 term value to 12, and the addition of a value 6, which in R'10 would have been 6.3.

Example 3 - Use of the R20 Series

Australian Standard AS 1303 - 1973 "Hard-drawn Steel Reinforcing Wire for Concrete"

TABLE 1.1 (page 4)

SIZES OF PLAIN WIRE

Size mm	Nominal area mm^2	Mass kg/m
4	12·6	0·099
5	19·6	0·154
6·3	31·2	0·245
7·1	39·6	0·311
8	50·3	0·395
9	63·6	0·499
10	78·5	0·616
11·2	98·5	0·773
12·5	122·7	0·963

Comments

New wire sizes were adopted during the change to metric [SI] units.

Wire sizes are taken from the R20 series, with two selections:

R20/2 (4.....6.3), using every second term; and
R20 (6.3......12.5), using every term in the series.

Example 4 - Use of the Derived R'10/3 Series:

International Standard ISO 1302 - 1974 (E) "Technical Drawings - Method of Indicating Surface Texture on Drawings"

TABLE 1 (page 3)

Roughness values R_a		Roughness grade numbers
µm	µin	
50	2 000	N 12
25	1 000	N 11
12,5	500	N 10
6,3	250	N 9
3,2	125	N 8
1,6	63	N 7
0,8	32	N 6
0,4	16	N 5
0,2	8	N 4
0,1	4	N 3
0,05	2	N 2
0,025	1	N 1

Comments

The table sets out a specification for surface roughness grades on mechanical drawings. The roughness values are expressed in micrometers and microinches, and are both taken from the R'10 series, using every third term. [If the values 3 and 31.5 had been used, the series would have been R10/3; however, by properly choosing 3.2 and 32, the more rounded derived series R'10/3 has been utilized.]

Note that by using a conversion factor of 25 [itself a preferred number in the R10 series], rather than the correct 25.4, both sets of values conform to one series.

Example 5 - Use of R'10 and R"20 with Modifications and Deletions

Australian Standard AS 1256 - 1973 "Preferred Metric Sizes of Hot-rolled Flat Steel Bars and Wrought Non-ferrous Rectangular Bars"

TABLE 4 (page 6)

ALUMINIUM AND ALUMINIUM ALLOY RECTANGULAR BARS

Width mm	Thickness* mm								
10	(1.6)	3							
12	1.6	3	4	6	10				
16	(1.6)	3	(4)	6	(10)				
20	(1.6)	3	4	6	10	12			
25	(1.6)	3	4	6	10	12	16	20	
32		3	4	6	10	(12)	(16)	(20)	
40		3	4	6	10	12	16	20	25
50		3	4	6	10	12	(16)	20	25
60		3	(4)	6	(10)	12	(16)	(20)	(25)
80		3	4	6	10	12	16	20	25
100		3	4	6	10	12	(16)	(20)	25
160				6	10	12	(16)	(20)	25

* Thicknesses in parentheses denote second choice sizes; all others are first choice sizes.

Comments

Widths of rectangular bars are selected from the R'10 series, with the modification of the 12.5 term value to 12, and the deletion of the 125 term value.

Thicknesses are chosen from the R"20 series, using every second step, and with deletions of the term values 2, 2.5, 5, and 8; thus thicknesses for an irregular R"20/2 series (1.6.......25) with deleted terms apply.

Example 6 - Use of the 1-2-5 Series [or R3 Series]

Australian Standard AS 1100.7 -1972 "Australian Standard Specification for SCALES - DRAWING PRACTICE"

TABLE 2 (page 3)

ARCHITECTURAL AND BUILDING SCALES

Full size				1:1
Reduction ratios	1:2 1:20 1:200 1:2000	1:2500	1:5 1:50 1:500	1:10 1:100 1:1000

Comments

The scale ratios recommended for use on architectural and building drawings represent a selection from the 1-2-5 Series (1.....2000), with the addition of a scale 1:2500, to link with surveying and mapping scales.

APPENDIX C: PREFERRED NUMBERS AND PREFERRED SIZES FOR USE IN ENGINEERING

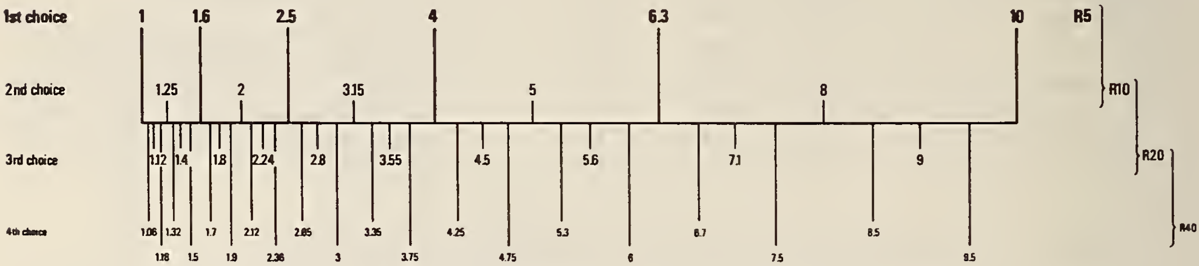
Insert PD 6481C : 1977 "Preferred Numbers and Preferred Sizes" to BSI [Standards Associates] PD 6481: 1977 "Recommendations for the Use of Preferred Numbers and Preferred Sizes."

Preferred numbers and preferred sizes

PD 6481C:1977

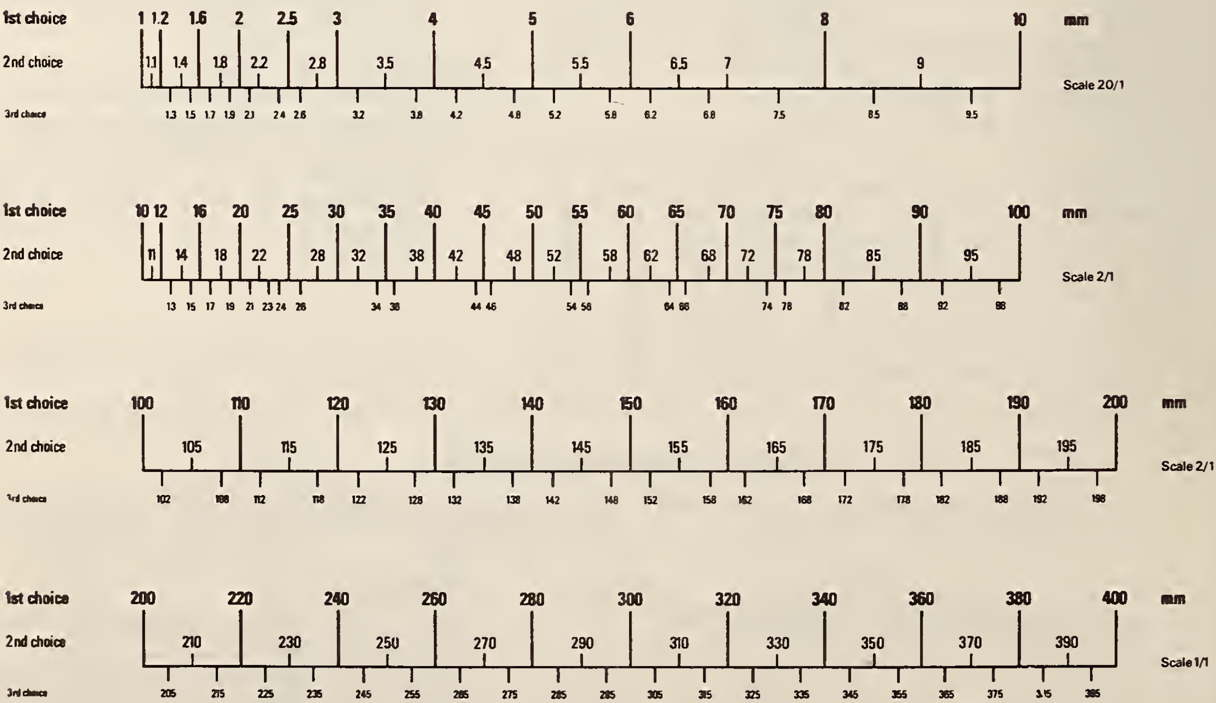
(Extracted from PD 6481:1977)

Preferred numbers



The series may be extended in either direction by multiplying or dividing by 10, 100, 1000 etc.

Preferred sizes



Continued similarly above 400 mm

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APPENDIX D: SIMULATED OUTPUT DATA FROM AN AUTOMATED APPROACH TO THE SELECTION OF PREFERRED METRIC VALUES

Example 1: Conversion and Rationalization of Minimum Uniform Live Loads [lbf/ft^2 to kPa]

INDEX OF CRITICALITY: D [± 5%]; PREFERENCES FROM TABLE 1 [CONVENIENT NUMBERS], page 17.

ITEM NO.	CUSTOMARY VALUE [lbf/ft^2]	EXACT CONVERSION [kPa]	CRITICALITY RANGE [kPa]	PREFERRED VALUES IN ORDER OF PREFERENCE [HIGHEST] [NEXT]	PERCENT VARIATION [%]	REVERSE CONVERSION TO CUSTOMARY UNITS
1001	30	1.436	1.364 - 1.508	1.5 1.4	+4.43 -2.53	31.33 29.24
1002	40	1.915	1.819 - 2.011	2.0 1.9	+4.43 -0.79	41.77 39.68
1003	50	2.394	2.274 - 2.514	2.5 2.4	+4.43 +0.25	52.21 50.12
1004	60	2.873	2.729 - 3.016	3.0 2.8	+4.43 -2.53	62.66 58.48
1005	75	3.591	3.411 - 3.771	3.5 3.6 *	-2.53 +0.25	73.10 75.19
1006	80	3.830	3.639 - 4.022	4.0 3.8 *	+4.43 -0.79	83.54 79.36
1007	100	4.788	4.549 - 5.027	5.0 4.8	+4.43 +0.25	104.43 100.25
1008	120	5.746	5.458 - 6.033	6.0 5.5 *	+4.43 -4.28	125.31 114.87
1009	125	5.985	5.686 - 6.284	6.0 5.8	+0.25 -3.09	125.31 121.14
1010	150	7.182	6.823 - 7.541	7.0 7.5**	-2.53 +4.43	146.20 156.64
1011	200	9.576	9.097 - 10.055	10.0 9.5**	+4.43 - .79	208.85 198.41
1012	250	11.970	11.372 - 12.569	12.0 12.5	+0.25 +4.43	250.62 261.07

Note: *If three preferences had been shown, the third preference would have consolidated the metric preferences for 75/80 and 120/125 lbf/ft^2 as 3.7 kPa and 5.8 kPa.
**The third preferences would be 7.2 kPa and 9.6 kPa, respectively.

POSSIBLE REPLACEMENT VALUES: [kPa]

1st Preference: 1.5, 2, 2.5, 3, [3.5], 4, 5, 6, 7, 10, 12

2nd Preference: 1.4, 1.9, 2.4, 3, 3.8, 4.8, 6, 7.5, 9.5, 12

Example 2: Stairways - Geometric Requirements [feet and inches to mm]

INDEX OF CRITICALITY: C [±2%]; PREFERENCES FROM SECTION 2.4 [PREFERRED DIMENSIONS]

ITEM NO.	CUSTOMARY VALUE [ft & in]	EXACT CONVERSION [mm]	CRITICALITY RANGE [mm]	PREFERRED VALUES IN ORDER OF PREFERENCE [HIGHEST] [NEXT]	PERCENT VARIATION [%]	REVERSE CONVERSION TO CUSTOMARY UNITS
1201	6'-6"	1981.2	1942 - 2021	2000 1950	+0.95 -1.57	6'-6.74" 6'-4.77"
1202	6'-8"	2032.0	1991 - 2072	2000 2050	-1.57 +0.87	6'-6.74" 6'-8.71"
1203	7'-0"	2133.6	2091 - 2176	2100 2150	-1.57 +0.77	6'-10.7" 7'-0.65"
1204	7 1/2"	190.5	186.7 - 194.3	190	-0.26	7.48"
1205	7 3/4"	196.8	192.9 - 200.8	200 195	+1.60 -0.93	7.87" 7.68"
1206	8"	203.2	199.1 - 207.3	200 205	-1.57 +0.87	7.87" 8.07"

APPENDIX E: REFERENCES

1. References Dealing with SI Units and Conversion Factors

a. American National Standard ANSI Z 210.1 - 1976 / ASTM E 380 - 76[r] / IEEE Std. 268 - 1976
"METRIC PRACTICE" (1976 Revised Edition)

Issued by: ANSI - American National Standards Institute, New York
ASTM - American Society for Testing and Materials, Philadelphia
IEEE - Institute of Electrical and Electronics Engineers, New York

b. ANSI/ASTM E 621 - 78 "Standard Practice for the Use of METRIC (SI) UNITS IN BUILDING DESIGN AND CONSTRUCTION"
[Committee E-6 Supplement to ASTM E 380; based on NBS Technical Note 938]

c. U.S. Department of Commerce / National Bureau of Standards, Washington D.C.
NBS Technical Note 938 "RECOMMENDED PRACTICE FOR THE USE OF METRIC (SI) UNITS IN BUILDING DESIGN AND CONSTRUCTION"
[Reprinted June 1977]

2. References Dealing with Preferred Numbers and Preferred Number Series

a. ISO [International Organization for Standardization], Geneva, Switzerland
   i. ISO Standard 3 - 1973 "PREFERRED NUMBERS - SERIES OF PREFERRED NUMBERS"
   ii. ISO Standard 17 - 1973 "GUIDE TO THE USE OF PREFERRED NUMBERS AND OF SERIES OF PREFERRED NUMBERS"
   iii. ISO Standard 497 - 1973 "GUIDE TO THE CHOICE OF SERIES OF PREFERRED NUMBERS AND OF SERIES CONTAINING MORE ROUNDED VALUES OF PREFERRED NUMBERS"

b. American National Standards Institute, New York
American National Standard Z 17.1 - 1973 (Revision of Z 17.1 - 1958)
"American National Standard for PREFERRED NUMBERS"

c. Canadian Standards Association, Rexdale, Ontario, Canada
Canadian Standard CAN3-Z 234.3-77 "GUIDE FOR THE SELECTION AND USE OF PREFERRED NUMBERS"

d. British Standards Institution, London England
   i. British Standard BS 2045 : 1965 "PREFERRED NUMBERS"
   ii. Draft for Development DD 29 :1973 "Rules for and Guide to the Use of PREFERRED NUMBERS AND PREFERRED SIZES"
   iii. Published Document PD 6481 : 1977 "RECOMMENDATIONS FOR THE USE OF PREFERRED NUMBERS AND PREFERRED SIZES"
   [Supersedes BS 4318 and DD 29]

e. Standards Association of Australia, North Sydney, NSW, Australia
SAA Miscellaneous Publication MP 19-1970
"REPORT ON PREFERRED NUMBERS AND THEIR USE"

3. References Dealing with Rounding and Significant Places of Figures

a. American Society for Testing and Materials [ASTM], Philadelphia

ASTM E 29-67 (Reapproved 1973) "Standard Recommended Practice for INDICATING WHICH PLACES OF FIGURES ARE TO BE CONSIDERED SIGNIFICANT IN SPECIFIED LIMITING VALUES"

b. British Standards Institution, London, England

i. British Standard BS 1957 : 1953 "THE PRESENTATION OF NUMERICAL VALUES- (Fineness of expression; Rounding of numbers)"

ii. British Standard BS 2846 : 1957 "THE REDUCTION AND PRESENTATION OF NUMERICAL RESULTS"; prepared by J.T.Richardson (ICI)

c. Standards Association of Australia, North Sydney, NSW, Australia

Australian Standard AS 1565 - 1974 [Appendix H] "Rounding of Numbers"

4. References Dealing with Preferred Metric Dimensions and Sizes in Engineering

a. Canadian Standards Association, Rexdale, Ontario, Canada

i. Canadian Standard CAN3-G312.1-75 "PREFERRED METRIC DIMENSIONS FOR FLAT METAL PRODUCTS"

ii. Canadian Standard CAN3-G312.2M-76 "PREFERRED METRIC DIMENSIONS FOR ROUND, SQUARE, RECTANGULAR AND HEXAGONAL METAL PRODUCTS"

b. British Standards Institution, London, England

British Standard BS 4318: 1968 "RECOMMENDATIONS FOR PREFERRED METRIC BASIC SIZES FOR ENGINEERING (1mm to 300 mm)" [out of print and superseded by PD 6841 : 1977]

c. Standards Association of Australia, North Sydney, NSW, Australia

Australian Standard AS 1122 - 1973 "RECOMMENDED METRIC SIZES FOR ENGINEERING"

5. References Dealing with Preferred Metric Dimensions in Building

a. ISO [International Organization for Standardization], Geneva, Switzerland

i. ISO Standard 1006 - 1973 "MODULAR COORDINATION - BASIC MODULE"

ii. ISO Standard 1040 - 1973 "MODULAR COORDINATION - MULTIMODULES FOR HORIZONTAL COORDINATING DIMENSIONS"

b. Canadian Standards Association, Rexdale, Ontario, Canada

Canadian Standard CAN3-A31.M-75 "SERIES OF STANDARDS FOR METRIC DIMENSIONAL COORDINATION IN BUILDING"

Part 3: Controlling Dimensions in Building

Part 4: Recommended Metric Coordinating Dimensions for the Sizing of Building Components.

c. Standards Association of Australia, North Sydney, NSW, Australia

i. Australian Standard AS 1224-1972 "PREFERRED SIZES OF BUILDING COMPONENTS"

ii. Australian Standards AS 1233 and 1234 - 1972 "PREFERRED DIMENSIONS IN BUILDING"

d. British Standards Institution, London, England

British Standard BS 4330 : 1968 "Recommendations for the Coordination of Dimensions in Building - CONTROLLING DIMENSIONS"

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This Technical Note contains a comprehensive examination of considerations involved in the selection of preferred metric values during the change to SI in the U.S. construction community. It has been prepared to assist those engaged in the conversion and rationalization of technical data for use in design and production to make informed judgments during the selection of metric values.

The adoption of preferred metric values and the concomitant rationalization of the technical data base will be one of the main benefits of the change to metric (SI) units. The principal aim is to encourage the choice of simple, convenient, or preferred metric values and ranges of rational values, rather than exact or marginally rounded soft conversions of existing values which will generally require a second change to more workable numbers at a later stage. The Technical Note has three parts:

1) background information on number systems and properties of numbers, metric impact, and alternative conversion strategies;

2) alternative preferred number concepts for individual values, sets of related values, and series of preferred values; and,

3) a methodology for the determination and selection of preferred metric values in technical information by means of a manual or an automated approach.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Convenient numbers; metrication; number systems; preferred numbers; rationalization; selection of metric values; series of numbers; SI.

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